1

FINAL REPORT

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Groundwater Contamination Study Forbes Field Air National Guard Base Shawnee County, Kansas

Prepared For:
United States Air Force
Occupational and Environmental
Health Laboratory (OEHL)
Brooks Air Force Base, Texas

September 1985

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A groundwater contamination study was performed at Forbes Field ANGB. The field investigation was conducted from November, 1984 to September 1985 and included the installation of 12 monitor wells, collection and analysis of groundwater samples from the monitor wells and collection and analysis of soil samples. The groundwater and soil samples were analyzed for oil and grease concentrations. Based on the findings of the sampling and analytical work, additional investigations have been recommended at the site.

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GROUNDWATER CONTAMINATION STUDY

FINAL REPORT

FORBES FIELD
AIR NATIONAL GUARD BASE
SHAWNEE COUNTY, KANSAS

UNITED STATES AIR NATIONAL GUARD
AIR NATIONAL GUARD HEADQUARTERS
ANDREWS AIR FORCE BASE, MARYLAND

SEPTEMBER 1985

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PREPARED FOR

UNITED STATES AIR FORCE
OCCUPATIONAL AND ENVIRONMENTAL HEALTH LABORATORY (OEHL)
BROOKS AIR FORCE BASE, TEXAS 78235

PREFACE

Roy F. Weston, Inc. (WESTON) has been retained by the U.S. Air Force Occupational and Environmental Health Laboratory (OEHL) under Contract F33615-80-D-4006, to provide general engineering, hydrogeological and analytical services. OEHL has authorized WESTON, under Task Order 0051 dated 17 September 1984, to conduct a Groundwater Contamination Study at Forbes Field ANGB. The findings, conclusions, and recommendations of this study are contained herein.

The Groundwater Contamination Study at Forbes Field ANGB was conducted under the auspices of staff personnel of Roy F. Weston, Inc. and was managed through WESTON's Bannockburn, Illinois office. The following personnel served lead functions in the performance of this project.

Mr. Peter J. Marks, Program Manager
Ms. Katherine A. Sheedy, P.G., Project Manager
Mr. Walter M. Leis, P.G., Geosciences QA Officer
Mr. Robert J. Karnauskas, P.G., P.HG., Project Coordinator
Mr. Mark A. Hutson, Project Hydrogeologist
Dr. Earl Hansen, Laboratory Manager
Mr. Richard Balmer, Assistant Project Geologist
Ms. Elizabeth M. Uhl, Assistant Project Hydrogeologist

WESTON expresses sincere thanks to the Base personnel at Forbes ANGB for their assistance and cooperation throughout this project.

This work was accomplished between November 1984 and September 1985. Major Robert D. Binovi, Environmental Quality Branch, USAF Occupational and Environmental Health Laboratory (USAF OEHL) was the technical monitor.

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EXECUTIVE SUMMARY

INTRODUCTION

Forbes Field Air National Guard Base (ANGB) Topeka, Kansas has served as a training center intermittently since 1942 and is currently occupied by the Kansas Air National Guard (KSANG) 190th Air Refueling Group. Fuel storage and handling facilities in support of Base flight missions represent a potential source of contamination if inadvertent releases occur to the environment.

WESTON has been retained by the United States Occupational and Environmental Health Laboratory (OEHL) under Contract No. F33165-80-D-4006 to provide general engineering, hydrogeological and analytical services. KSANG requested assistance from OEHL in the evaluation of known and suspected releases of jet fuel (JP-4) to the environment of Forbes Field ANGB. Task Order No. 0035 was subsequently issued for a pre-survey effort at the KSANG facility.

The pre-survey at Forbes Field ANGB consisted of a site inspection and collection of all available background information. The purpose of this pre-survey was to obtain sufficient information to develop a work scope and cost estimate for the performance of a preliminary field investigation to identify the potential presence of contaminants in the subsurface environment at Forbes Field ANGB.

The pre-survey report for Forbes Field was submitted in April, 1984. Following modifications in the scope of work, Task Order 0051, dated 24 September 1984, was issued, which authorized a field investigation at Forbes Field. The purpose of this report is to document the accomplishment of this field investigation. Acronyms, terms, nomenclature and units of measurement used in this report are defined in Appendix A. A copy of the formal Task Order authorizing this work is included here as Appendix B.

PURPOSE AND SCOPE OF INVESTIGATION

The purposes of this Task Order are as follows:

- To determine if soil and groundwater contamination have resulted from fuel storage, distribution, and use at Forbes Field.
- To provide estimates of the magnitude and extent of contamination, if any.
- To identify potential environmental consequences of migrating pollutants.

- To identify any additional investigations and their attendant costs necessary to identify the magnitude, extent, and direction of movement of discovered contaminants.

The scope of work included the performance of the following tasks:

- Inspection of the storm sewer system for the purpose of identifying locations in the storm sewers of continued JP-4 infiltration, if any.

- The performance of a soil boring and sampling investigation designed to delineate the potential presence of JP-4 contamination in the unsaturated and saturated zones on KSANG property.

- The installation of twelve groundwater monitoring wells on-site to enable assessment of horizontal and vertical groundwater flow and contaminant movement within unconsolidated sediments and bedrock.

- The completion of an elevation survey to establish casing elevations of the monitoring well network.

- Performance of field baildown tests on six wells to provide estimates of subsurface permeability.

MAJOR FINDINGS

Based on the analyses performed, levels of contamination were found in soils and groundwater that warrant further investigation and possible future action.

A total of ten representative soil samples, which exhibited positive field instrumentation response, were selected for laboratory analysis for oil and grease. The analytical data indicates concentrations of oil and grease typically in the 25 to 50 ppm range at the sampling locations. The oil and grease concentrations were substantially high at Boring B-10 (adjacent to fueling hydrant 8-A) and SW-5 (adjacent to the intersection of the storm sewer and fuel pipeline from pumphouse E) where concentrations were reported of 686 ppm and 829 ppm, respectively. Fuel hydrant 8-A is a known location of fuel leakage and well SW-5 encountered a thin floating phase of fuel.

Nine of the twelve water samples collected from the monitoring wells contained oil and grease at concentrations above the detection limit of 0.10 mg/l, while the remaining three samples had no detectable oil and grease.

Concentrations of oil and grease range from a high of 3,970 mg/l in well SW-5 to below detection limits in wells DW-2, DW-3, and DW-4. Those wells finished in the unconsolidated materials above bedrock generally show greater concentrations than those cased into competent rock.

The above data suggest that the oil and grease related compounds are moving to the northwest off the Base property at low concentration. Further dilution and dispersion can be expected to occur as the migration distance increases. The significance of this off-site migration will be dependent on the specific organic compounds which comprise the oil and grease concentrations reported.

CONCLUSIONS

Based on the results of this study at Forbes Field ANGB, the following key conclusions have been drawn:

General Conclusions

- Unconsolidated sediments at the Base consist of clays and silty clays which were apparently weathered from underlying materials. Bedrock consists of shales with interbedded limestones and some sandstone stringers.

- Groundwater beneath Forbes Field ANGB occurs under water table conditions in the unconsolidated sediments above bedrock and under confined conditions within permeable zones of bedrock.

- General groundwater flow is from east to west toward the unnamed tributary to Shungunuga Creek which is located at the northwest edge of the Base.

- In areas where natural unconsolidated materials overlie bedrock, an upward component of flow exists from bedrock into the unconsolidated materials.

Presence of Contaminants

- Concentrations of oil and grease in excess of the taste and odor threshold were found in nine of the twelve groundwater monitoring wells sampled.

- Oil and grease was found in all ten soil samples submitted for chemical analysis.

- A floating layer of fuel 0.20 feet thick was found in shallow monitor well SW-5.

- The presence of oil and grease in deep monitor well DW-1, which is located upgradient of suspected source areas on the Base, indicates the potential that contaminants are migrating onto the Base from other areas.

Migration of Contaminants

- Contaminants may enter the groundwater flow system by percolating through surficial materials or by introduction to the shallow bedrock in locations where overlying materials have been removed. Trenching for construction of sewers and fuel lines has created conduits for migration of contaminants into bedrock and laterally to the storm sewer system. This is evidenced in well SW-5 where fuel has accumulated in backfill materials surrounding a fuel distrubution line and by past discharges of fuel to the storm sewer system.

- The fate of contaminants migrating from Base facilities in groundwater is to travel laterally toward the tributary to Shunganuga Creek which flows along the western boundaries of the Base. It is not known if contaminants have now reached this point.

Significance of Findings

- The effects on the environment of any contaminants which may leave the Base are unknown at this time. The identity of the specific compounds leaving the Base must be known before this determination can be made.

- The relatively low levels of contamination encountered in the majority of locations tested seems to indicate that much of the fuel released to the environment by the known leaks has been either flushed from the subsurface or cleaned up by base efforts.

- Contaminant levels appear to diminish rapidly with distance from source areas. This trend is expected to continue as distance from the source is increased.

RECOMMENDATIONS

The principal goal of this study at Forbes Field Air National Guard Base was to determine whether or not environmental degradation was occurring as a result of materials handling practices at the installation. The results presented in Section 4 confirm that the groundwater and soils in the immediate area of fuel handling installations have been affected. These preliminary findings require additional verification which is discussed below. These recommendations are intended to evaluate whether contaminants are leaving the Base, and if so, which contaminants and at what concentrations.

The following additional work is recommended for Forbes Field ANGB.

1) An additional round of samples should be taken from existing wells DW-1 through DW-6 and SW-1 through SW-6 to verify the results obtained from the first sampling round. The parameters tested should be expanded to include U.S.EPA Priority Pollutant volatile organic compounds, plus xylene.

2) Five additional groundwater monitoring wells should be constructed between Base facilities and the drainage way on the northwest side boundary. Four wells should be installed along the northwest boundary to determine if groundwater quality is being impacted at the downgradient edge of the property. Three of these wells should be completed in the unconsolidated deposits to monitor migration in the upper flow system. The remaining well should be a deep well located to monitor contaminant migration in the bedrock flow system. The fifth well should be installed at the northeast corner of the bulk fuel storage tank farm near the head of the surface water drainage ditch. Samples from these wells should be analyzed for the expanded parameter list.

3) Surface water samples should be collected from three locations in the drainage ditch on the northwest property boundary. One sample should be collected upstream of the bulk fuel storage area. The second sample should be collected mid-way between bulk fuel storage and the storm sewer outfall. The third sample should be collected from the area of the storm sewer outfall. Analysis of these samples should be for the expanded list of analyses.

4) At least one shallow monitoring well should be installed on the eastern edge of the site to monitor contamination possibly migrating on site from the east in the upper aquifer.

5) During collection of the next round of samples, the elevation of the stream bottom should be surveyed to determine whether the stream is recharging the groundwater system.

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Forbes Field Air National Guard Base (ANGB) Topeka, Kansas has served as a training center intermittently since 1942 and is currently occupied by the Kansas Air National Guard (KSANG) 190th Air Refueling Group. Fuel storage and handling facilities in support of Base flight missions represent a potential source of contamination if inadvertent releases occur to the environment.

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- The completion of an elevation survey to establish casing elevations of the monitoring well network.

- Performance of field baildown tests on six wells to provide estimates of subsurface permeability.

1.3 BASE PROFILE

The Kansas Air National Guard (KSANG) occupies Base facilities located at Forbes Field, Kansas. Forbes Field is located approximately three miles south of Topeka in Section 31, Township 12 South, Range 16 East in Shawnee County, Kansas. Figure 1-1 is an index map showing the location of the KSANG facilities.

The area surrounding the KSANG facility is a mixture of agricultural, light industrial and residential land usage activities. Former Air Force facilities are now used by a variety of industries. The village of Pauline, Kansas, is located adjacent to the Base on the west boundary.

Forbes Field was opened in 1942 as the Topeka Army Air Corps Base. The Base mission at that time was to provide operational training of heavy bombardment crews. At the end

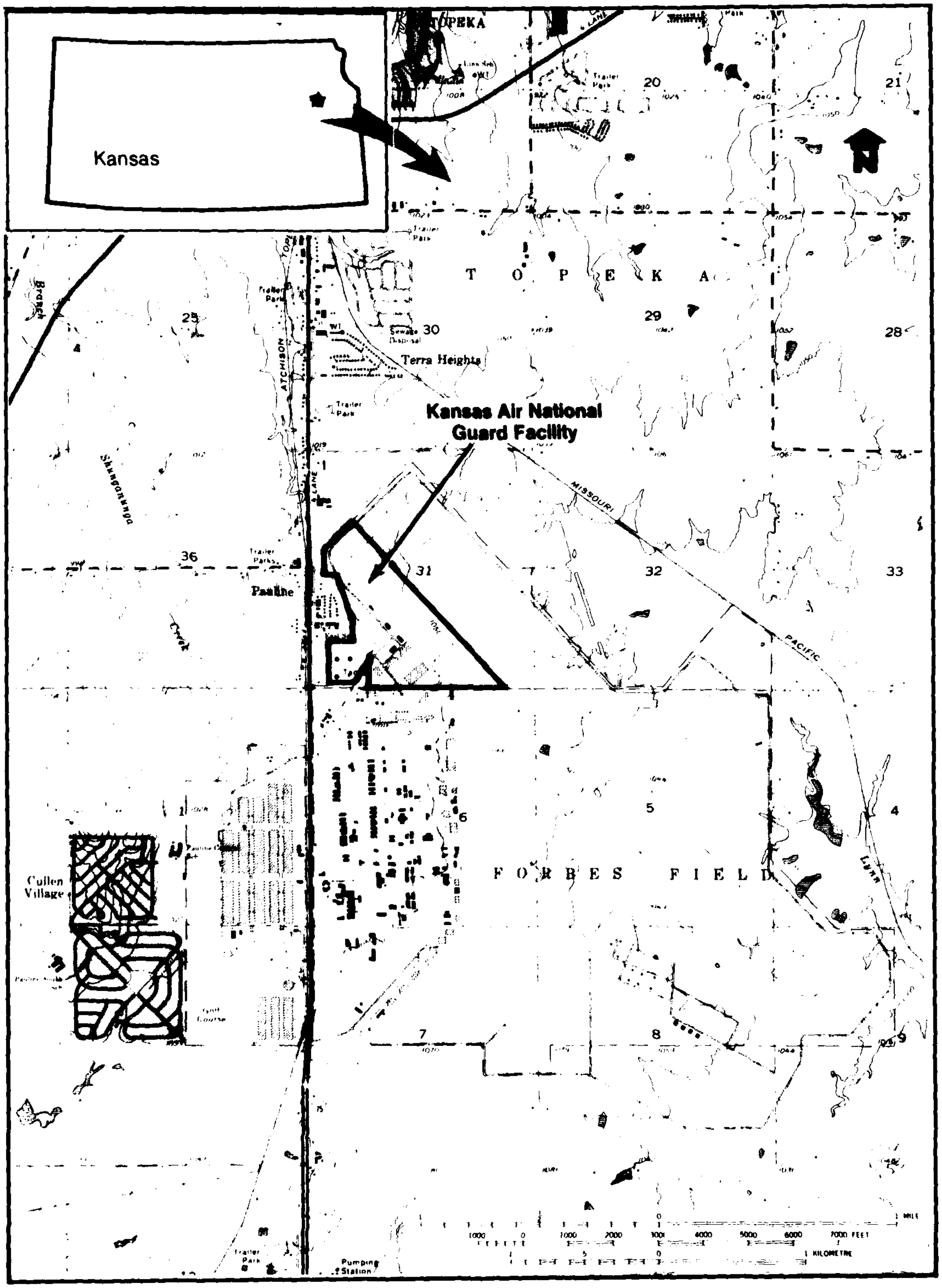


FIGURE 1-1 LOCATION MAP

of World War II the Base was closed and the hangars were used for grain storage.

During the period from 1948 to 1949 the Base was reopened for use by reconnaissance and geodetic survey wings of the Army Air Corps. The Base was renamed the Forbes Air Base during that time.

Forbes Air Base was reopened in 1951 with a mission of training bomber crews. In 1954, the Forbes Air Base and all existing facilities were transferred to the U.S. Air Force, and the installation was officially designated Forbes Field Air Force Base. The installation was assigned to the Strategic Air Command (SAC) until July 1965, when it was transferred to the Tactical Air Command (TAC) 12th Air Force and 838th Air Division.

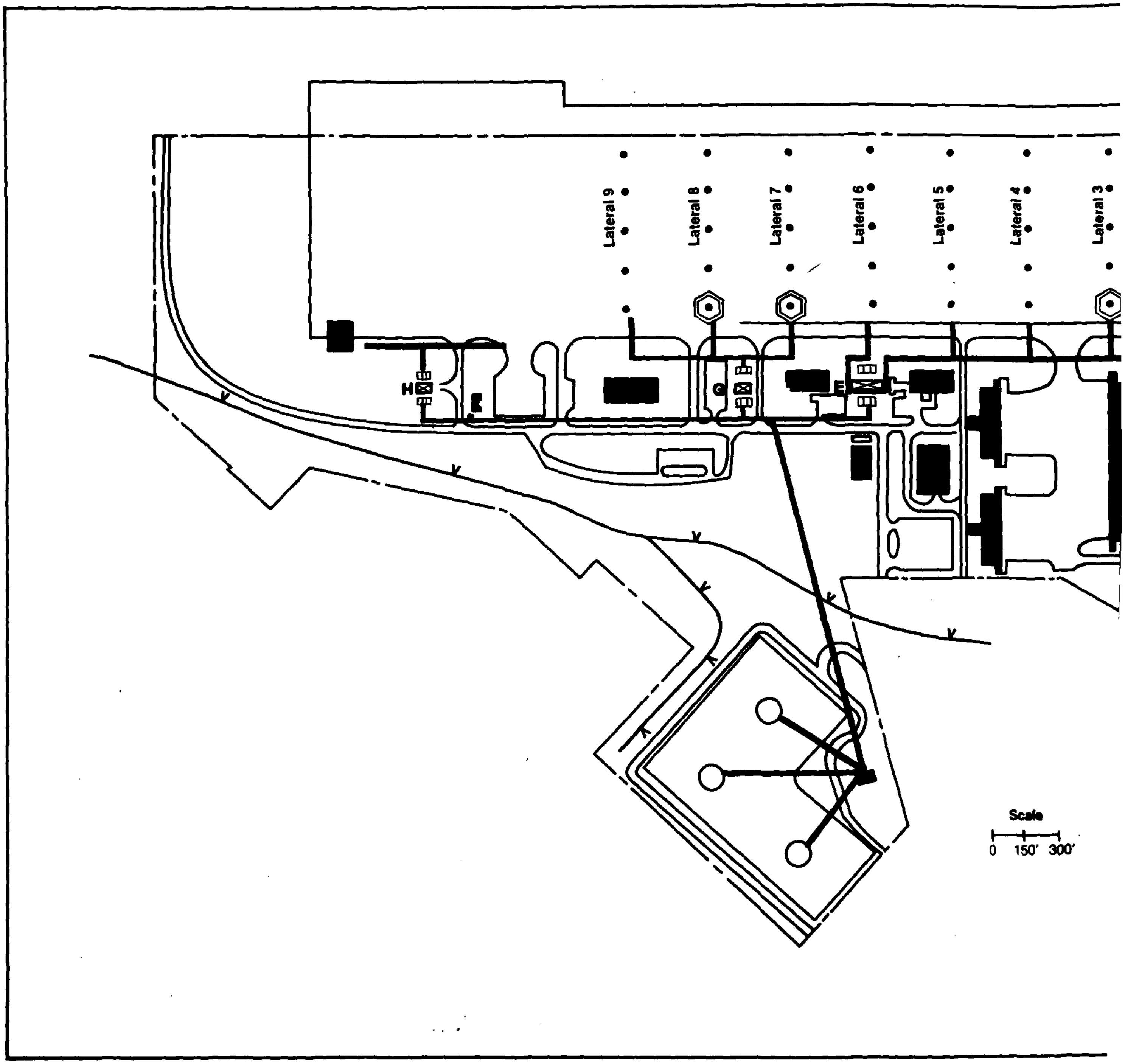
Forbes Field Air Force Base was closed in 1973 at which time the Kansas Air National Guard (KSANG) 190th Air Refueling Group was the only remaining activity on base, located on the northwest corner of the property.

The KSANG Base maintains jet fueling and storage facilities on the Base as shown on The Base Facility Map in Figure 1-2. Above ground storage facilities consist of three tanks located within earth diked berms. Two of the tanks have a 45,000 barrel (BBL) capacity with one tank having a 55,000 BBL capacity for storage of jet fuel (JP-4). All of the above ground storage tanks have floating roofs.

From the above ground storage tanks, jet fuel is piped to three pumphouses designated E, G, and H. On either side of each pumphouse are a number of smaller capacity buried fuel storage tanks as follows:

Pumphouse	Number of Buried Tanks	Tank Capacity (Each)
E	8	1190 BBL
G	6	1190 BBL
H	6	1190 BBL

From each pumphouse jet fuel is piped to a main distribution line from which laterals extend underneath the fueling ramp area. Currently in operation are laterals 1 through 6 operating from pumphouse E, and laterals 7 through 9 operating from pumphouse G. Along each lateral are five fueling hydrants designated A through E. Other structures on the Base include offices, hangars and other facilities in support of the Base mission.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Lateral 3
Scale
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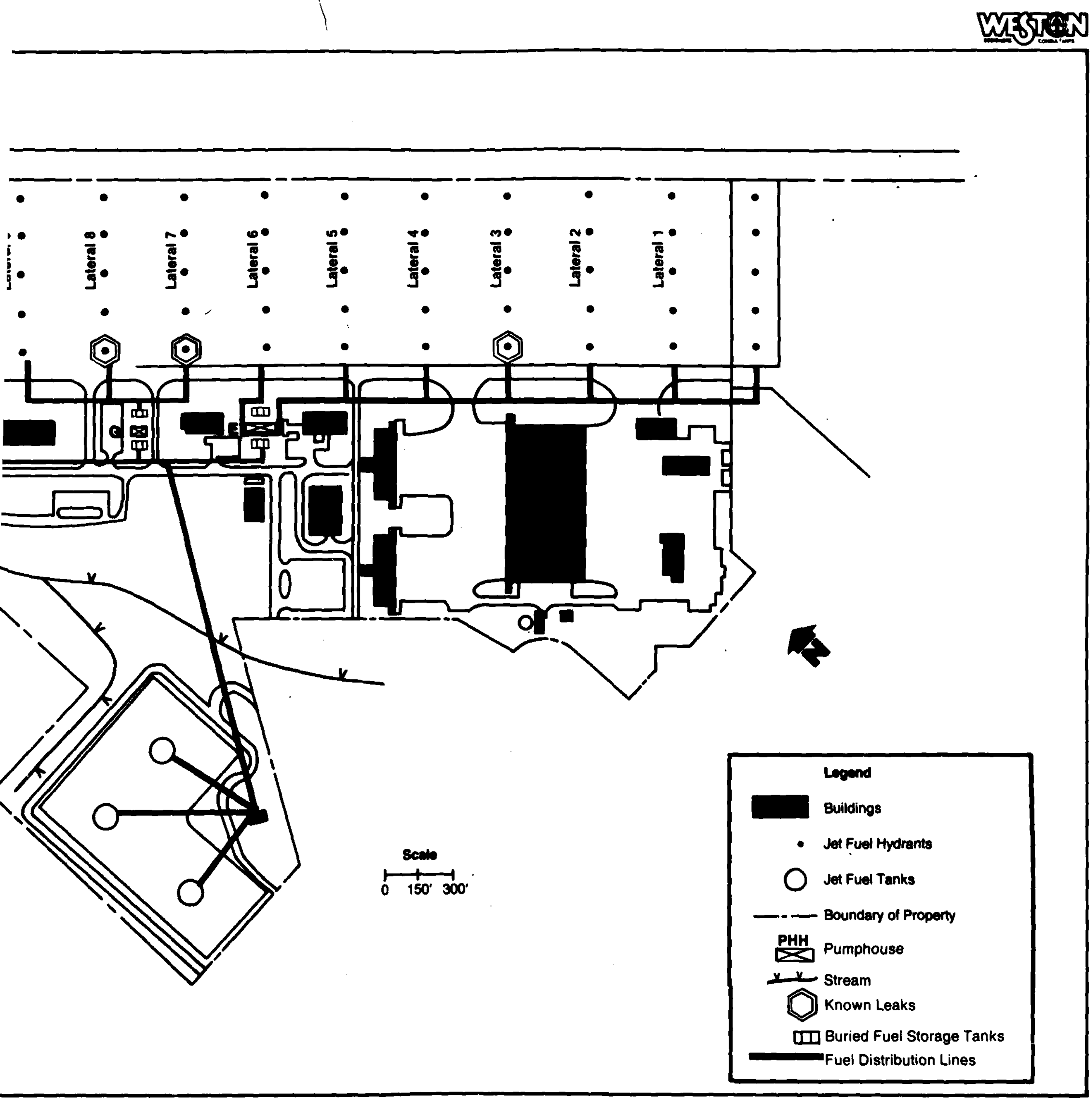


FIGURE 1-2 BASE FACILITY MAP

On 10 June 1983, JP-4 was observed emanating from concrete pavement joints adjacent to fuel hydrant 8-A when lateral 8 was routinely checked on the same date.

During pressurization to locate the leak, an unknown amount of JP-4 was released under the concrete pad and subsequently migrated to a storm drainage box culvert at the far northwest corner of the KSANG property. Approximately 1/8 inch of apparent JP-4 was observed on the storm drainage water which flows into an unnamed tributary to Shungunuga Creek. The fuel was contained on KSANG property and spilled materials were subsequently cleaned up.

Leaks have also occurred at fuel hydrants 7-A and 3-A in July and December of 1982, respectively, during which undetermined amounts of JP-4 were released. All known leakages from the system have occurred at the first welds of fueling hydrants along the respective laterals. Base personnel became concerned and in June 1983 requested an evaluation to determine the extent of possible groundwater contamination from the JP-4 releases as well as the general integrity of the hydrant fueling system.

1.4 CONTAMINATION PROFILE

Potential environmental contamination at Forbes Field may exist because of leaks and spills from JP-4 storage and handling at base facilities. Oil and Grease was chosen by OEHL as an indicator parameter to be used to detect contamination by JP-4 in the groundwater. The details of the field work accomplished are described in Section 3 of this report.

1.5 PROJECT TEAM

This investigation was conducted by staff personnel of Roy F. Weston, Inc., in Bannockburn, Illinois and was managed through WESTON's home office in West Chester, Pennsylvania. The following personnel performed lead functions in this project:

MR. PETER J. MARKS, PROGRAM MANAGER: Corporate Vice President and Manager of Laboratory Services, Master of Science (M.S.) in Environmental Science, 19 years of experience in laboratory analysis and applied environmental sciences.

MR. FREDERICK BOPP, III, PH.D., P.G. PROJECT MANAGER: Manager of the Geosciences Department, Doctor of Philosophy (Ph.D.) in Geology and Geochemistry, Registered Professional Geologist (P.G.), over 9 years of experience in hydrogeology and applied geological sciences.

MR. ROBERT J. KARNAUSKAS, P.G., P.HG. SENIOR PROJECT HYDROGEOLOGIST: M.S. in Hydrogeology and M.S. in Water Resources Management, over 8 years of experience in hydrogeology and applied geological sciences.

MR. MARK A. HUTSON, PROJECT HYDROGEOLGIST: Bachelor of Science (B.S.) and Graduate Study in Geological Sciences, over 4 years experience in hydrogeology and applied geological sciences.

MR. WALTER M. LEIS, P.G., GEOTECHNICAL QUALITY ASSURANCE OFFICER: Corporate Vice President M.S. in Geological Sciences, Registered Professional Geologist, over 11 years experience in hydrogeology and applied geological sciences.

MR. RICHARD C. BALMER, ASSISTANT PROJECT GEOLOGIST: B.S. in Geological Sciences, over 4 years experience in hydrogeology and applied geological sciences.

Professional profiles of these key personnel, as well as other project personnel are contained in Appendix C.

1.5.1 Subcontracting

The drilling and well installation work for this project was performed by Terracon Consultants, Inc., of Lenexa, Kansas. The well elevation survey was completed by Max A. Baker of Topeka, Kansas, a licensed surveyor in the state of Kansas.

SECTION 2

ENVIRONMENTAL SETTING

2.1 GEOGRAPHY

Forbes Field is located in the Dissected Till Plains section of the Central Lowlands Physiographic Province. The area around Forbes Field is characterized by gently undulating relief dissected by incised surface drainage. Local relief at Forbes Field is primarily the result of dissection by erosional activity associated with Shungunuga Creek. Surface elevations on the Base range from a low of approximately 1020 feet above mean sea level (MSL) along the northwest corner of the property to a high of approximately 1057 feet above MSL at the southeast corner of the property. Local drainage is predominantly to the west-northwest to an unnamed tributary of Shungunuga Creek.

2.2 SITE GEOLOGY

Sedimentary rocks of Paleozoic age overlie the Precambrian basement complex in the area of Forbes Field. The sedimentary deposits are typically composed of shales, limestones, and thin sandstones which record a distinctive cyclic pattern of sedimentation (Johnson and Adkison, 1967). Glacial drift deposited during the Kansan/Glaciation covers bedrock in some sections of the area. The drift is composed of clays, silts, and sands derived from local bedrock.

The entire area lies in the western part of the Forest City Basin. Outcropping rocks strike approximately N20E to N30E, and dip northwest at generally 20 to 40 feet per mile.

The geology of Forbes Field ANGB consists of interbedded marine shales and limestones of the Scranton Shale, Howard Limestone and Severy Shale Formations. Glacial drift forms a thin veneer over the bedrock in some portions of the area. A thin layer (5-20 feet) of unconsolidated sediments composed of clays and silty clays is present above the bedrock formations. These deposits are apparently weathered from the underlying shales.

2.3 HYDROGEOLOGY

Groundwater is found within both the unconsolidated surficial deposits and the bedrock formations beneath Forbes Field. Within the unconsolidated sediments water is found at shallow depths (4-12 feet) under unconfined conditions.

Water in the bedrock formations occurs predominantly in the limestone and sandstone beds and stringers which are interbedded within shales. Groundwater in these formations is present under confined conditions.

Groundwater flow horizontally across the site is generally from the west. The confined nature of groundwater within the bedrock formations creates an upward vertical gradient. Specifics of groundwater flow beneath the site are addressed in Section 4.

Water obtained from the formations involved in this study is of insufficient quantity to be used extensively for domestic water supplies. The Base and the adjoining village of Pauline, Kansas, are both served by a public water supply system.

SECTION 3

METHODS OF INVESTIGATION

3.1 SCHEDULE OF ACTIVITY

On 20 November 1984 WESTON met with representatives of the Civil Engineering, Security, Fire Protection, and Flight Operations Departments at Forbes Field ANGB to review the goals of the investigation, review drilling procedures and locations, and to establish the field schedule. An inspection of the storm sewers in the areas of suspected contamination was performed on the same day. Drilling locations were marked and clearances obtained on 21 November 1984. Soil borings and monitoring well construction commenced on 12 December 1984 and were completed by 4 January 1985. Groundwater sampling was completed on 5 January 1985. Table 3-1 is a summary of WESTON's field activities schedule at Forbes Field ANGB.

3.2 STORM SEWER INSPECTION

In order to evaluate areas of potential contamination, a survey of the storm sewer system on and adjacent to the refueling ramp was conducted. Previous observations by KSANG personnel noted the presence of JP-4 along the fuel laterals and storm sewers which were apparently serving as conduits for JP-4 migration from the leak source(s). A total of 23 manholes were inspected and surveyed with an Organic Vapor Analyzer (OVA) and an HNu Photoionization Detector (HNu) as well as visual observation. The valve control pit at the end of each lateral was also opened and the interior monitored with the OVA and HNu instruments.

In addition, four water samples were collected from manholes along the southwest side of the ramp at the end of lateral four, six, seven, and eight. These samples were allowed to come to room temperature before the headspace gasses were tested with HNu and OVA meters for the potential presence of volatile organic compounds. The operation of the OVA and HNu meters are described in detail in Section 3.3.2.

3.3 DRILLING PROGRAM

The field investigation at Forbes Field ANGB included the installation of 12 groundwater monitoring wells and the completion of 10 soil borings to recover subsurface soil samples for chemical analysis. The work was conducted by a drilling crew of Terracon Consultants, Inc., of Lenexa, Kansas. The drilling rig used to complete the work was a truck mounted CME 55 auger drill. The locations of all soil borings and monitoring wells were cleared by a representative of the Base Civil Engineering Department prior to drilling.

TABLE 3-1

FIELD ACTIVITY SCHEDULE

Date	Activity
20-21 November 1984	Initiation of field activity meeting with Base personnel to coordinate activities. Inspection of storm sewer manholes for evidence of JP-4. Establish boring locations for obtaining Base digging permits
12-29 December 1984	Soil borings and monitoring well installation
2-5 January 1985	Monitoring well development, sampling, and baildown tests
4 January 1985	Water level survey
8 January 1985	Well elevation survey

3.3.1 Decontamination of Drilling and Sampling Equipment

Decontamination of the drilling rig was performed prior to mobilization on-site to remove surface grease, oil and gasoline which could potentially affect the integrity of the field and laboratory data. This decontamination consisted of:

- Steam cleaning of the drill rig flat bed, tower and associated areas to remove as much grease, oil and gasoline as practical.

- Steam cleaning of the hollow steam augers inside and outside as well as compartments in which the augers were stored.

- Removal and steam cleaning of all tools to be utilized during drilling as well as compartments in which tools may be stored.

Split spoon barrels that were used for sample collection were subjected to the following decontamination protocol if field instruments (OVA and HNu meters) indicated the potential presence of contaminants:

- Disassembling of all continuous core barrel components.

- Scrubbing of continuous core barrel components in an Alconox solution.

- Clean water rinse.

- Acetone rinse.

- Clean water rinse.

Decontamination of the split spoon core barrels was required following collection of the following samples:

Boring No.	Sample No.	Boring No.	Sample No.
B-1	5	B-7	2
B-2	3	B-7	3
B-4	2	B-10	1
B-5	1	SW-3	2
B-5	3	SW-4	1
B-6	2	SW-4	3
B-6	3	SW-5	2

3.3.2 Field Instrumentation

The field instrumentation utilized on-site included an Organic Vapor Analyzer (OVA) and an HNu photoionization detector. The OVA is a portable unit using a flame ionization detector. It responds well to volatile organic components that are not per-halogenated (completely substituted with chlorine, fluorine or bromine).

The OVA is less sensitive to the presence of certain volatiles such as freon, carbon tetrachloride, or hexachloroethane. Information regarding the relative response of the OVA to various compounds is included in Appendix D.

The HNu portable photoionization device operates on light-induced ionization of carbon-carbon or carbon-nitrogen bonds. The unit used was equipped with a 10.2 electron volt (eV) lamp, which can detect all compounds with bond energies less than 10.2 eV. The HNu is particularly suited to the detection of volatile aromatic compounds such as benzene, toluene, ethylbenzene, xylenes and chlorobenzenes. It will not detect saturated alcohols, saturated amines, alkanes and saturated fluorochlorocarbons. Information regarding the relative response of the HNu to various compounds is included in Appendix E.

Due to differences in relative response and detectability of some compounds by each instrument, the OVA and HNu provide complimentary information. These instrument differences were effectively utilized in the field assessment of the presence of volatile organics at each boring location. Naturally occurring methane gas from decomposing biological material is suspected where high OVA and low HNu readings are recorded: the OVA has a 100% relative response factor for methane, while methane is not detectable using the HNu. Methane is not of concern in this investigation with respect to the occurrence and distribution of contaminants on-site.

3.3.3 Use of Instrumentation in Sample Screening

The OVA and HNu probes were used to measure volatile components in the soil samples immediately following the splitting of the core by the on-site geologist. Representative portions of each sample were placed in a plastic bag with a zip-lock opening to provide an airtight seal. The bagged sample was broken and agitated in the bag to expose as much surface area to the air as possible. The probes of each instrument were then inserted through a small break in the seal and the readings obtained were noted. OVA and HNu readings obtained in this manner are recorded on the drilling logs included in Appendix F. Only separate subsamples of those soil samples which showed the potential for being contaminated on the basis of field screening were retained for chemical analysis.

3.3.4 Soil Borings

A total of 124 feet of continuously sampled soil borings were completed at the 10 locations shown in Figure 3-1. Each boring was advanced using continuous soil sampling methods consisting of five foot sample tubes (3 1/4" I.D.) which extended through and were driven below the center of standard six inch diameter hollow stem augers. As the augers rotate, the stationary core barrel was advanced through the soil by hydraulic pressure. In this manner, a continuous, relatively undisturbed soil sample was obtained.

Following the sample screening procedure discussed in Section 3.3.3, representative samples of those intervals which gave positive responses to both the OVA and HNu were collected. Samples were removed from the core barrel and placed in an amber colored glass sample jar using a freshly decontaminated knife. The sample used in the screening process was retained for preparing geologic logs. Soil samples collected for chemical analysis were cooled and shipped to WESTON's laboratory for analysis.

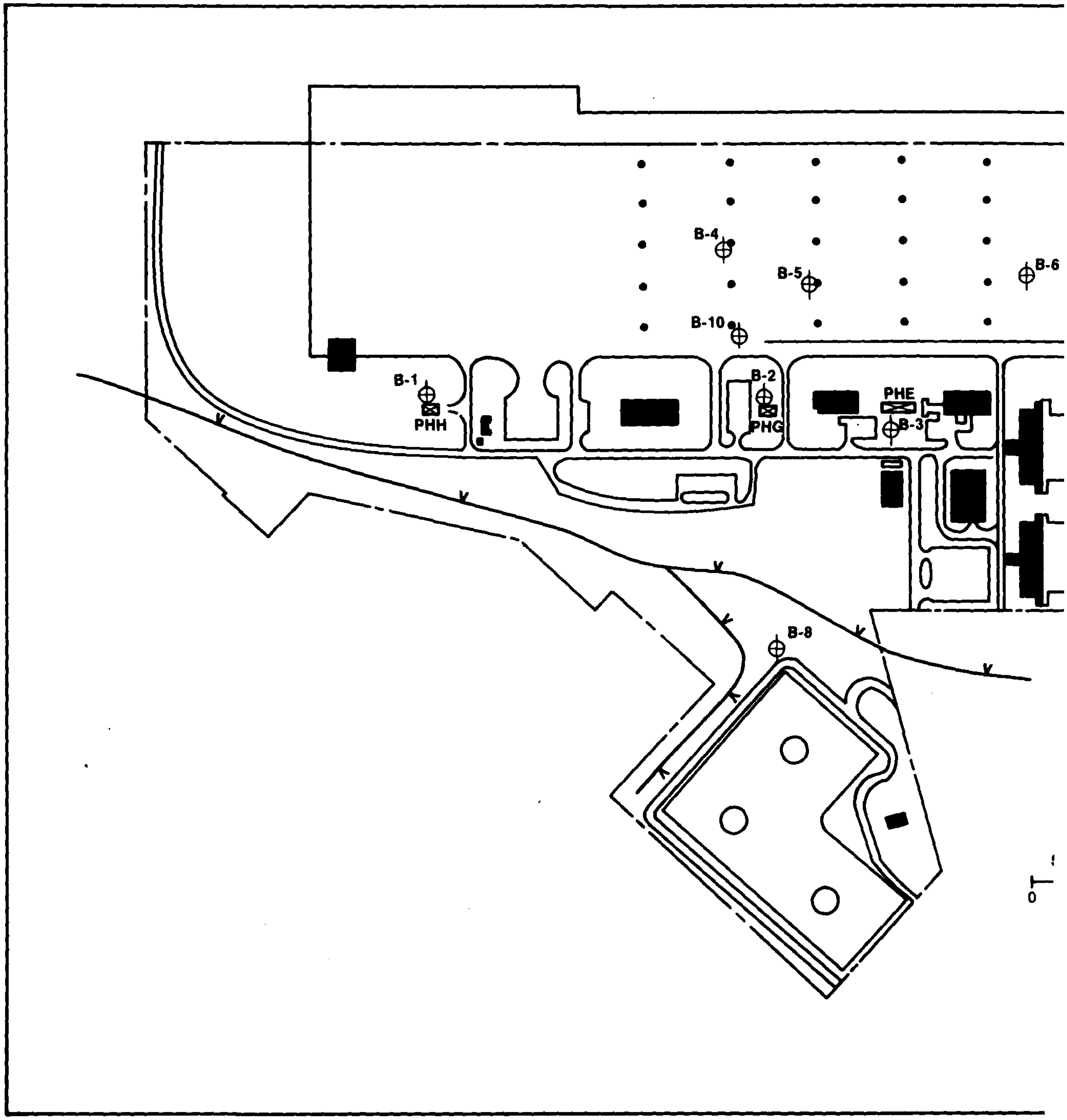
Drilling and sampling proceeded at five foot intervals until the borehole extended to a depth of three feet below the zone of saturation, or encountered bedrock, whichever was less. Depths of borings ranged from a minimum of four feet to a maximum of 18.8 feet. Geologic logs were prepared for each boring and are included in Appendix F of this report.

Each borehole was abandoned by backfilling with the drill cuttings. Those borings which extended through concreted areas of the Base were capped by a cement patch of the same thickness as the original surface.

3.3.5 Shallow Monitoring Well Installation

Six groundwater monitoring wells were installed in the unconsolidated materials which overlie bedrock and in the backfill materials which surround buried pipelines. Monitoring wells SW-2, SW-3 and SW-5 were installed in fill. Wells SW-1, SW-4 and SW-6 were installed in natural unconsolidated materials. The location of each shallow monitoring well is indicated on Figure 3-2.

The boreholes for installation of the wells were advanced to three feet below the water table or to bedrock by the same boring, screening, and sampling procedures described in Sections 3.3.3 and 3.3.4. Subsurface conditions permitted the augers to be removed from the bore hole without significant caving before inserting well materials. Wells were constructed of 2-inch diameter, schedule 40, flush joint, threaded PVC screen and riser pipe. Graded sand was


B-4
B-5
B-6
B-10
B-1
PHH
B-2
PHG
PHE
B-3
B-8
0

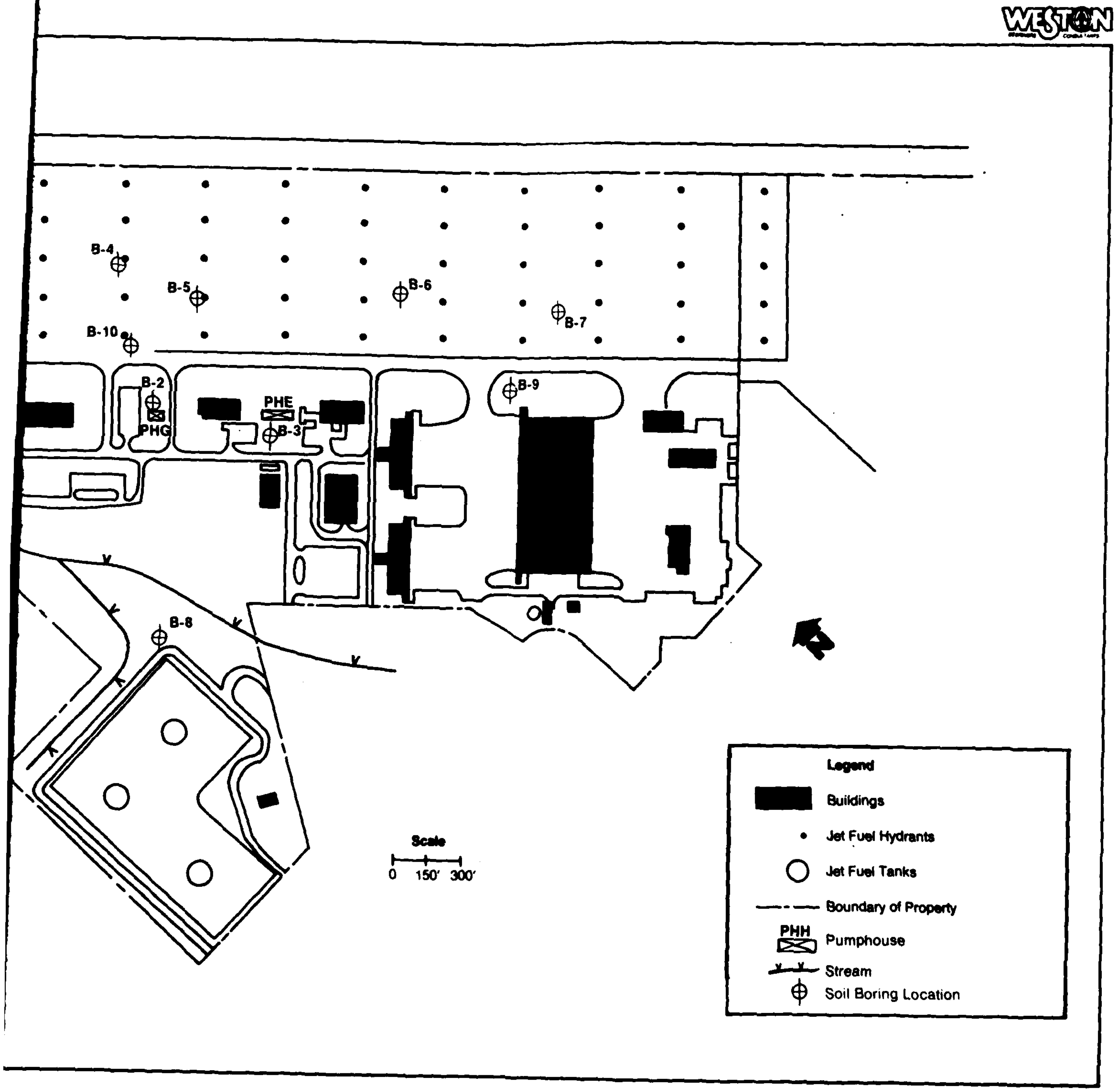
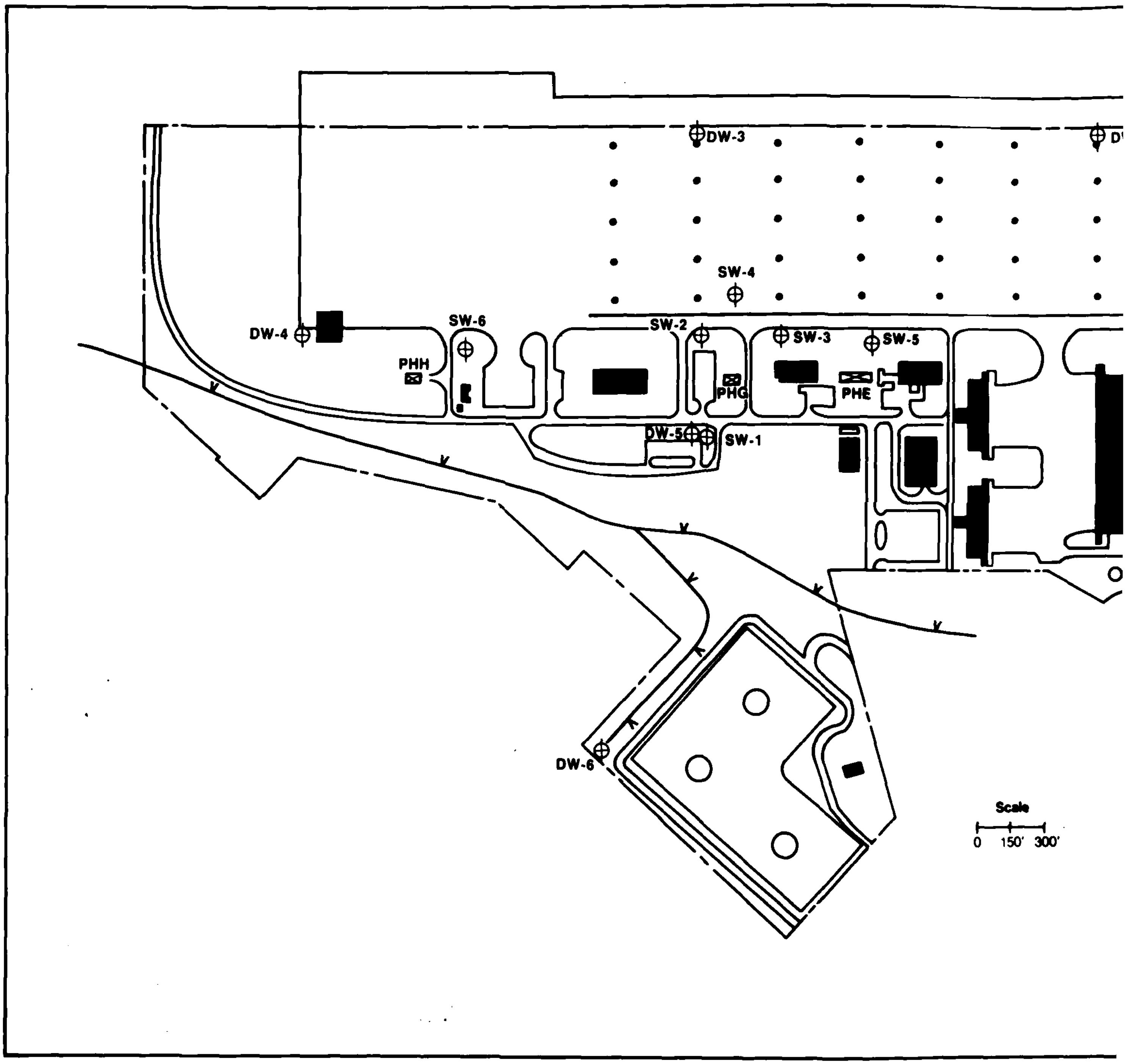


FIGURE 3-1 SOIL BORING LOCATIONS

2


DW-3
SW-4
DW-4
SW-6
PHH
SW-2
PHG
SW-3
SW-5
PHE
DW-5
SW-1
DW-6
Scale
0 150' 300'

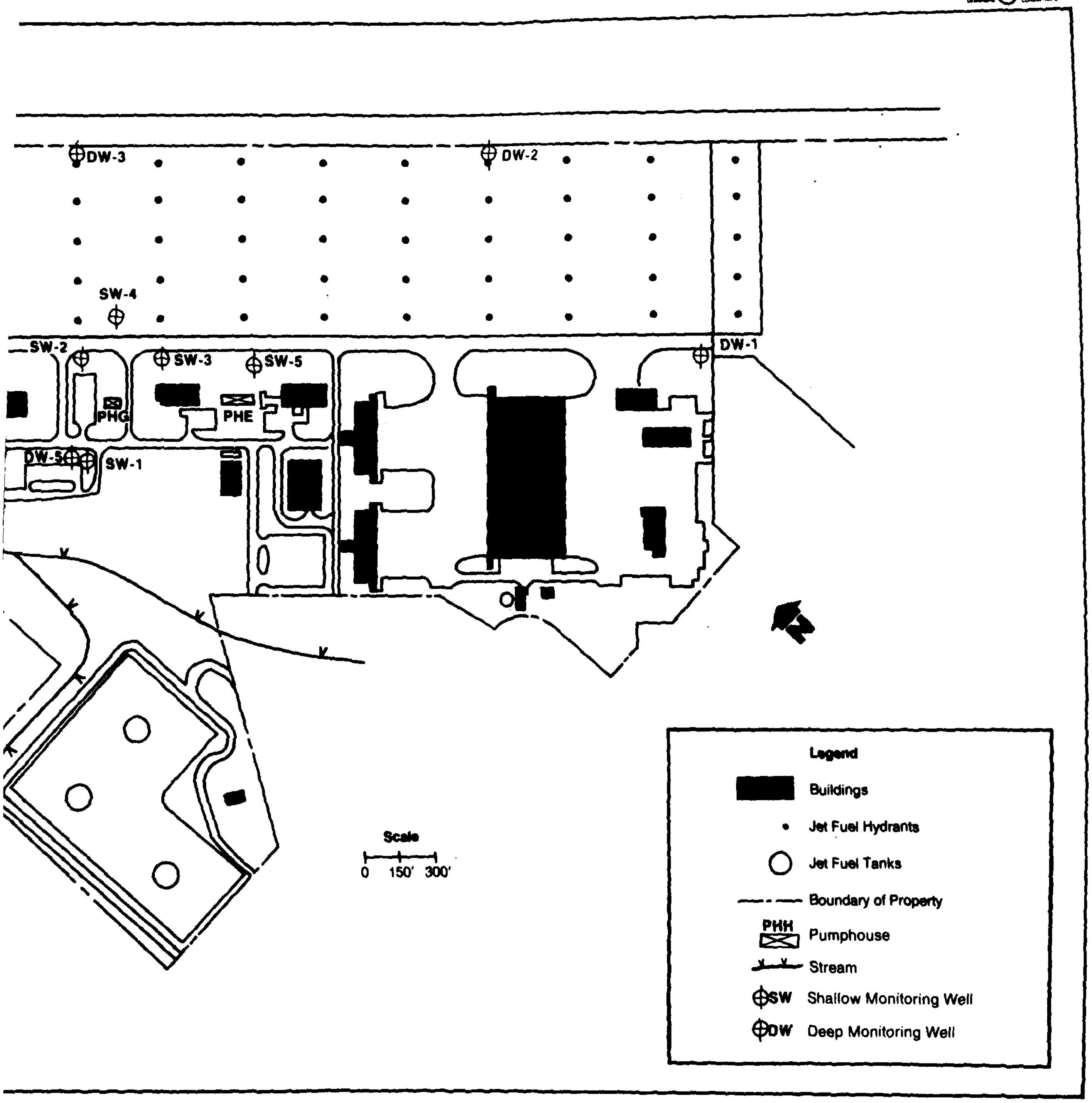


FIGURE 3-2 MONITORING WELL LOCATIONS

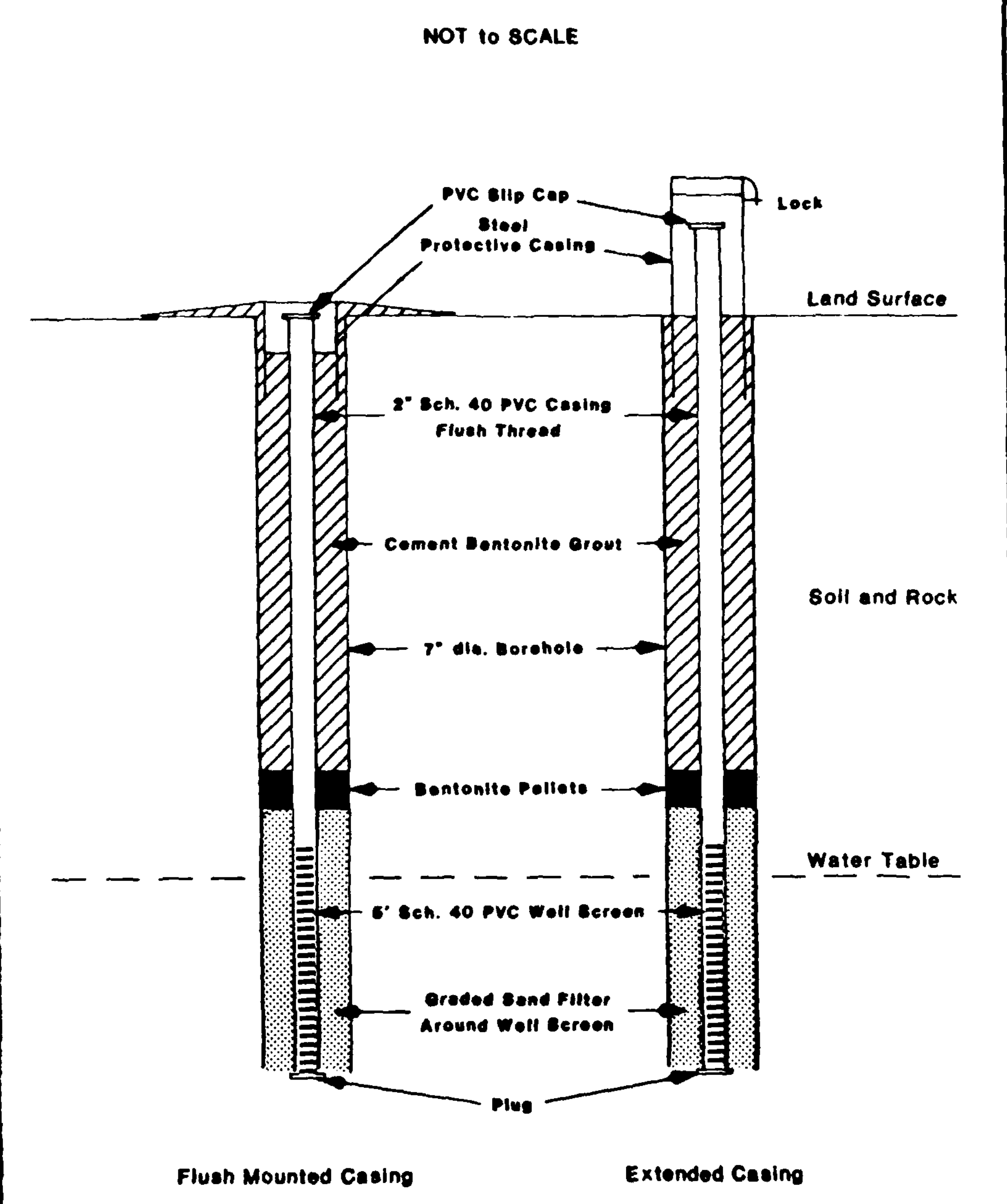
poured into the annular space around the well screen to a height of at least one foot above the top of the screened interval. A one foot thick layer of bentonite pellets was placed on top of the sand pack to seal the screened interval from vertical infiltration through the annular space. The seal was completed by pouring a cement-bentonite grout mixture into the annular space. Care was taken to produce a continuous grout seal above the sandpack. Each well was completed with the installation of a protective steel casing that was cemented in place over the top of the well seal. Flush mount protective casings were required for the wells installed on the ramp to prevent interference with aircraft traffic. Wells installed in grassy areas of the Base were completed with 1.5 to 2 feet of stick-up above ground level.

Typical well construction details for wells constructed in both concreted and grassy areas of the Base are included in Figure 3-3. Well completion summaries for all shallow monitoring wells are presented in Appendix F and summarized in Table 3-2. Each well was developed by bailing a minimum of three times the volume of standing water in each of the well casings at which time the wells were clear.

3.3.6 Bedrock Monitoring Well Installation

Six deep monitoring wells were installed in the shale and limestone bedrock below the site to evaluate the depth to groundwater, detect the presence of fuel contamination in the bedrock aquifer, and determine the directions of groundwater flow below the Base. The location of each of these wells is indicated in Figure 3-2.

Initial drilling for each bedrock monitoring well was completed by drilling an 8-inch hole through the unconsolidated materials and five feet into competent bedrock using standard wash-rotary techniques with a clean water drilling fluid. Four-inch, schedule 80, PVC casing was inserted to the bottom of the boring. A cement-bentonite ground mixture was pumped through a tremie pipe down the outside of the casing to the bottom of the hole and the annular space was grouted to the surface. After the grout had set at least 24 hours, a 3.50 inch diameter open hole was drilled through the casing to 30 feet below the first anticipated water bearing zone using the same methods. Typical well construction details for deep monitoring wells installed in both concreted and grassy areas of the Base are included in Figure 3-4. Well completion summaries for all deep monitoring wells are presented in Appendix F and are summarized in Table 3-2.



ROY F. WESTON, INC. WESTON ENVIRONMENTAL CONSULTANTS-DESIGNERS	SCHEMATIC FOR SHALLOW MONITORING WELLS	FIGURE NO. 3-3

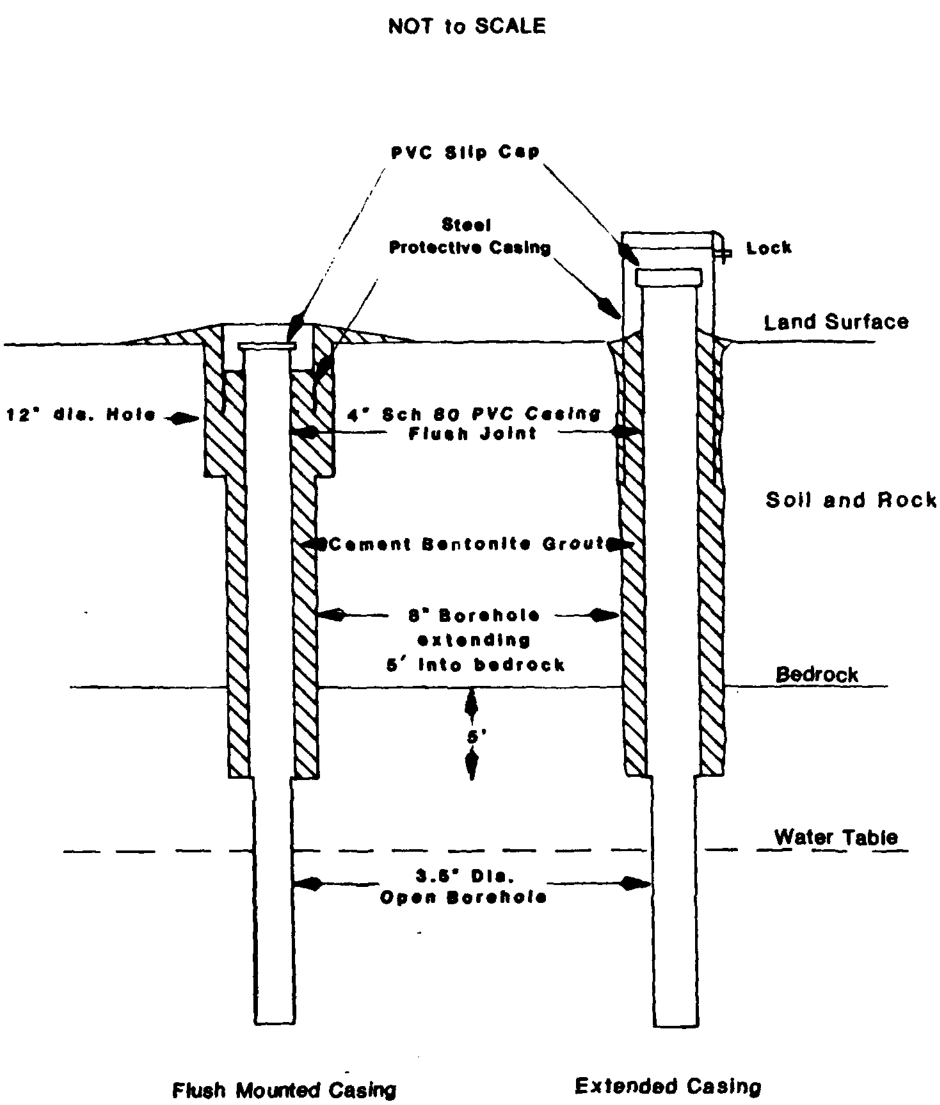
TABLE 3-2

SUMMARY OF WELL CONSTRUCTION DETAILS
FORBES FIELD AIR NATIONAL GUARD BASE
TOPEKA, KANSAS

Well #	Land Surface Elevation in Feet	Top of PVC Casing, Elevation in Feet	Top of Steel Casing, Elevation in Feet	Screened Interval Depth in Feet	Sandpack Interval Depth in Feet
SW-1	1032.51	1034.42	1034.55	5-10	4-10
SW-2	2038.27	1040.06	1040.44	3-8	2.5-8.5
SW-3	1037.82	1039.87	NA	11-16	9.5-16.5
SW-4	1039.64	1039.40	1039.54	6-11	5-11
SW-5	1039.64	1042.03	1042.48	1.7-7.7	1.8-7.7
SW-6	1033.11	1034.91	1035.23	6.9-11.9	6-11.9

Well #	Land Surface Elevation in Feet	Top of PVC Casing, Elevation in Feet	Top of Steel Casing, Elevation in Feet	Open Interval Depth in Feet
DW-1	1049.35	1050.82	1051.96	21.1-55
DW-2	1052.85	1052.65	1053.06	23.1-52.7
DW-3	1048.41	1048.37	1048.51	22.2-48.2
DW-4	1033.51	1034.70	1036.34	22.2-48.2
DW-5	1032.48	1034.21	1035.82	16.8-60
DW-6	1034.37	1036.39	1037.26	20.4-50

Elevations referenced to Mean Sea Level (MSL)
NA-Not Available



WESTON

SCHEMATIC FOR DEEP MONITORING WELLS

FIGURE NO. 3-4

Following completion of drilling, each well was developed by blowing water out of the well with compressed air to remove drill cuttings from the well. Monitoring of the drilling fluid and cuttings with the OVA and HNu instruments indicated no organic vapors were present. Drilling fluids and cuttings were containerized in steel drums for subsequent collection and disposal by Base personnel.

3.4 Groundwater Sampling

Groundwater samples were collected from each of the 12 monitoring wells for Oil and Grease analysis during the period from 2 January to 5 January, 1985. Samples were collected following well development to assure that only fresh, representative groundwater was obtained. All sampling equipment was decontaminated prior to sampling at each well. The bailer was scrubbed with a detergent solution, rinsed with clean water, sprayed with acetone and rinsed with distilled water. Clean equipment was wrapped in plastic bags for handling.

All required sample containers were prepared by WESTON laboratories in accordance with standard U.S.EPA or U.S. Air Force supplied procedures and protocols. The sample containers required for Oil and Grease analysis of each well consisted of a single one liter amber glass bottle preserved with sulfuric acid. The samples were cooled and shipped to WESTON's laboratory for analysis.

While taking groundwater samples for laboratory analyses the WESTON field team also analyzed grab samples from each well for temperature, specific conductance, and pH. The pH was measured with an Orion Model 201 portable pH meter. The instrument was calibrated with a standardized pH=7 solution before each measurement. Specific conductance was measured with a Horizon Model 1484-10 portable conductivity meter which was calibrated to a standardized 1900 umho solution, before each measurement. A pocket thermometer was used to record temperature. Each of these measurements was done in quadruplicate to assure that a representative value was obtained. Results of this testing are presented in Table 3-3.

In addition to the samples collected from each well, a duplicate sample and field blank were prepared for QC/QA purposes. The field blank was prepared by pouring distilled water into a sample bottle while in the field. Field sampling sheets which document the above procedures are included in Appendix G. Sample chain-of-custody documentation is contained in Appendix H. Standard

TABLE 3-3

SUMMARY OF WATER QUALITY FIELD TESTING

Well	T°C	pH*	Specific Conductance* (umhos/cm)
SW-1	12	7.18	1227
SW-1 (Duplicate)	12	7.18	1227
SW-2	12	6.75	1200
SW-3	11	6.64	2175
SW-4	11	7.95	1975
SW-5	11	6.91	935
SW-6	13	6.83	1881
DW-1	14	7.12	1394
DW-2	13	7.19	1294
DW-3	13	7.03	1449
DW-4	14	6.69	1185
DW-5	14	8.58	2153
DW-6	12	7.60	2025

*Average of Four Readings

laboratory analysis protocols used in the analysis of these samples are contained in Appendix I.

3.5 GROUNDWATER ELEVATION SURVEY

The PVC casing elevation of all 12 monitoring wells were surveyed to the nearest 0.1 foot by a State of Kansas licensed surveyor. The purpose of the survey was to establish references from which to measure depth to groundwater so that the watertable and piezometric surface gradients and directions of flow could be established. All elevations were referenced to permanent benchmarks located on the Base property. Table 3-4 presents a summary of well elevations and construction details.

3.6 WATER LEVEL MEASUREMENTS

Three rounds of water level measurements were made. Two rounds were made at the time of sampling during the period January 2-5, 1985, and another round was made independent of sampling activities on 4 February, 1985. All readings of monitoring wells were referenced to the top of PVC casing using a steel surveyor tape and chalk. Table 3-4 summarizes all calculated water surface elevations.

During the process of measuring water levels, each well was checked for the presence of floating fuel. The thickness of fuel was determined by coating a steel tape with water sensitive paste and subtracting the depth to fuel from the depth to water.

3.7 BAILDOWN RECOVERY TESTS

Baildown recovery tests were performed on six of the monitoring wells to evaluate subsurface permeability. A baildown test measures the rate of recovery of the water level in a well after an instantaneous withdrawal. Because the wells penetrate materials of varying permeability, the test results represent an averaged permeability of the strata open to the well. Baildown test data and the reference used in analyzing this data are included in Appendix J.

TABLE 3-4

SUMMARY OF MONITORING WELL
WATER ELEVATION SURVEY
FORBES FIELD AIR NATIONAL GUARD BASE
TOPEKA, KANSAS

Well #	GROUNDWATER ELEVATIONS 1-3-85	1-4-85	2-4-85
SW-1	1025.32	1023.67	1025.24
SW-2	1035.81	1035.82	1035.56
SW-3	1030.67	1030.82	1030.38
SW-4	-	1029.62	1029.67
SW-5	1035.75	1035.67	1035.07
SW-6	1022.78	1022.84	1022.43
DW-1	1043.15	-	1041.87
DW-2	1038.77	1040.56	1040.65
DW-3	-	1031.07	1034.20
DW-4	1024.92	1016.81	1022.69
DW-5	1027.22	1027.22	1025.44
DW-6	-	1022.50	1023.47

- Well not recovered following development

SECTION 4

INVESTIGATION RESULTS

4.1 STORM SEWER MANHOLE INSPECTION

The inspection of the Base storm sewer system with OVA and HNU instruments revealed no detectable organic vapors in any of the manholes along the ramp. A slight sheen was however detected floating on the surface in the manhole located northeast of Building 665. Base personnel theorized that one of the shops on site may have disposed of waste oily materials in an open manhole. The sheen could also have been produced by seepage of fuel into the sewer from surrounding materials.

Organic vapors were detected in the air inside the control valve pits at the end of laterals seven, eight and nine. These organic odors are likely associated with the known leaks at fueling hydrants 7A and 8A. The occurrence of the odors in the control valve pits, confirmed by accounts of Base personnel of JP-4 accumulations shortly after the leaks were discovered, suggests the backfill materials around the fuel pipelines have acted as conduits for JP-4 migration from the leakage points.

Headspace analysis of the water samples collected from the sewer near the end of lateral eight showed a concentration of volatile organic vapors of 15 parts per million (ppm) in air. Each of the other water samples collected showed no detectable organic vapors. This data confirmed that the areas of the Base around laterals seven, eight and nine would be the areas most likely to be contaminated with JP-4. Subsequent portions of the investigation were designed to evaluate the potential existence of contamination in the soil and groundwater in those areas. The results of manhole and storm water screening with the OVA and HNU instruments are presented in Table 4-1. Manhole and stormwater collection locations are illustrated in Figure 4-1.

4.2 SITE GEOLOGY

Based on the geologic records reviewed during the pre-survey effort and the borings completed during this investigation, the entire base is underlain by 10-20 feet of clays and silty clays which were apparently derived from weathering of the underlying bedrock formations. A thin veneer of Glacial Drift, composed of silty clays and sands, is known to cover bedrock in some portions of the general area, but was not encountered in the borings completed for this study.

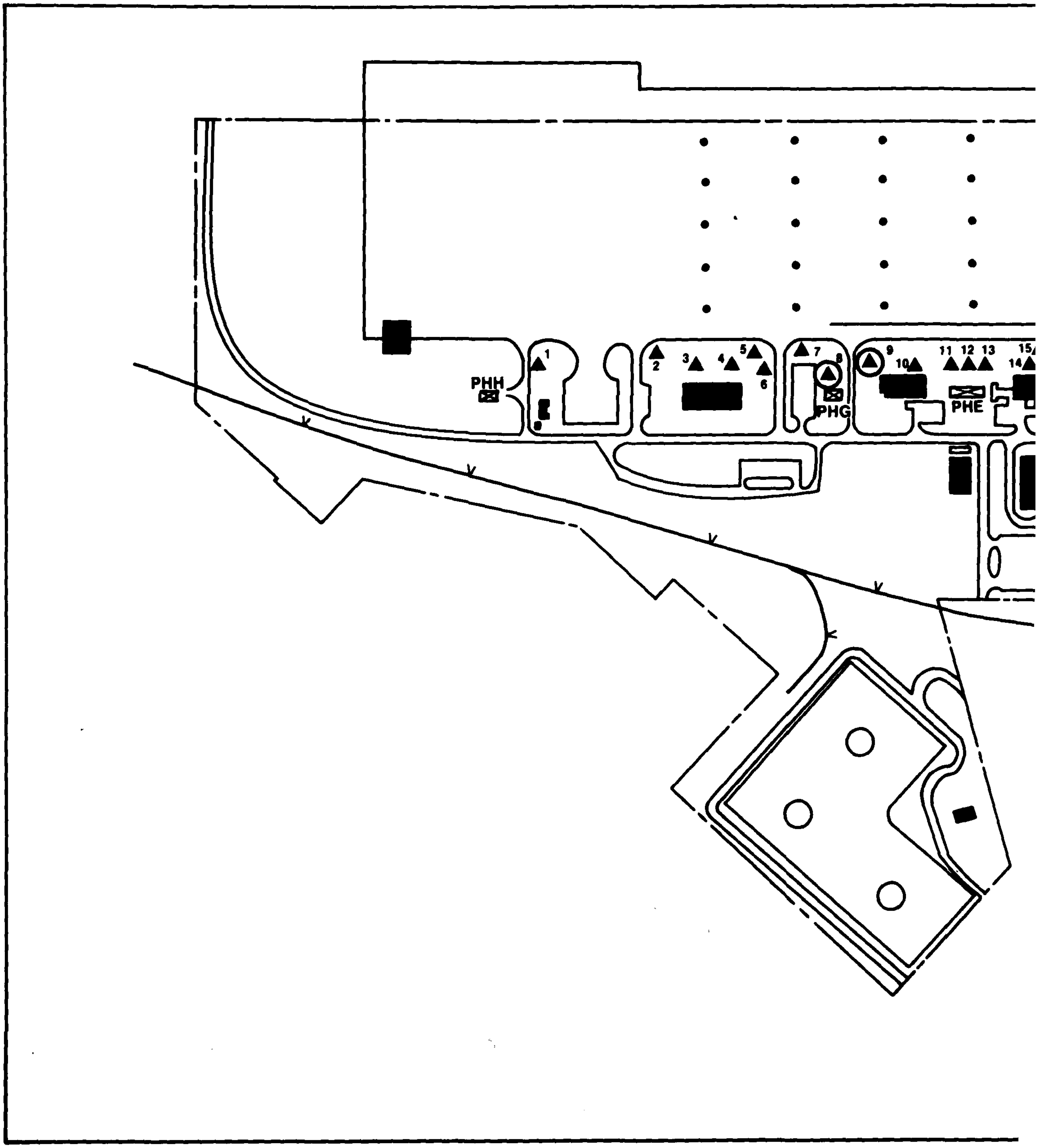
TABLE 4-1

MANHOLE FIELD SCREENING DATA
(Screened 11/20/84)

Manhole #	HNU (ppm)	OVA (ppm)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0

STORMWATER SCREENING RESULTS
(Collected and screened 11/21/84)

Manhole #	HNU (ppm)	OVA (ppm)
8	15	0
7	0	0
17	0	0
20	0	0


PHH
PHG
PHE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

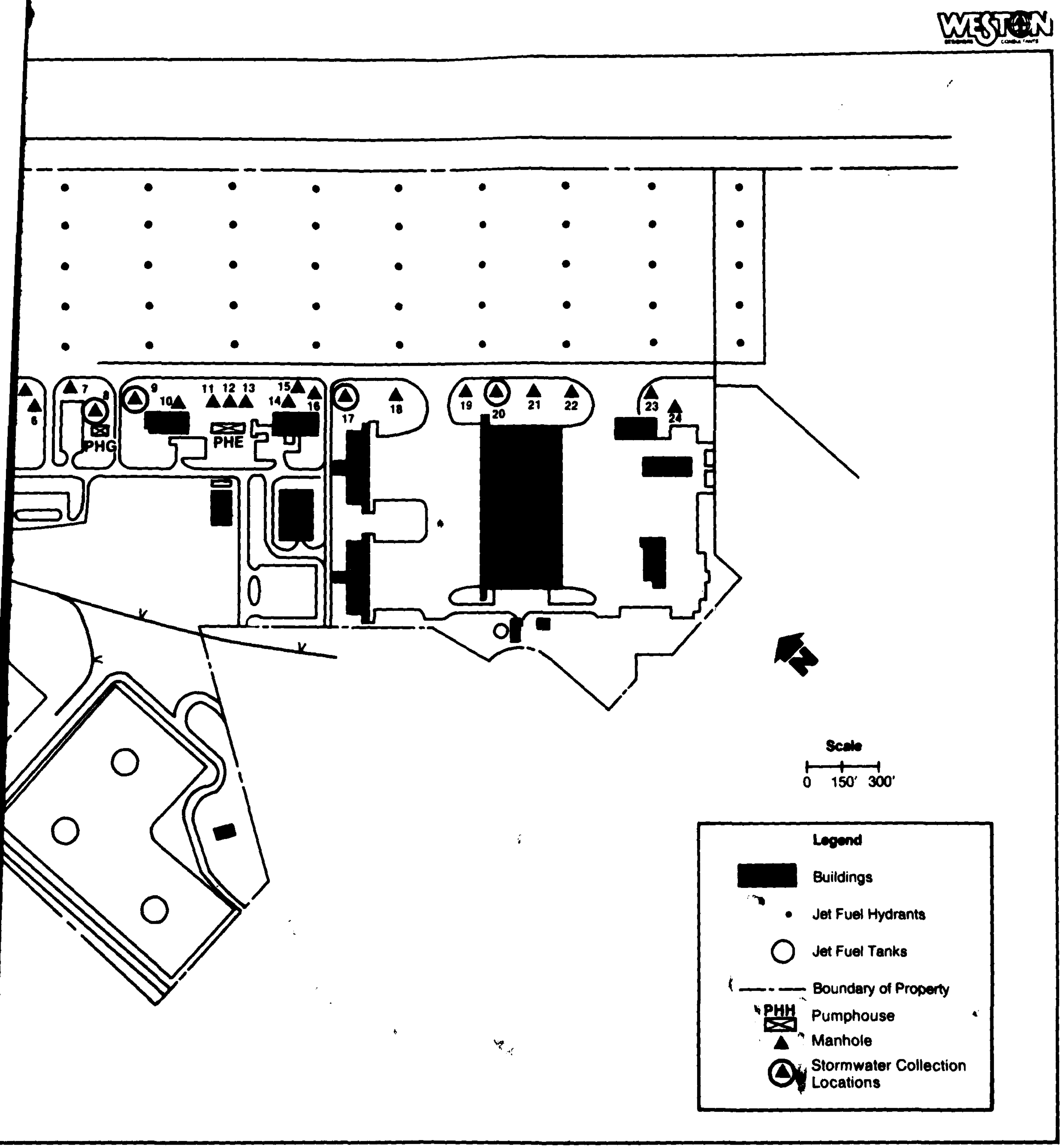


FIGURE 4-1 MANHOLE AND STORMWATER COLLECTION LOCATIONS

Structural fills were encountered in various areas of the Base. These fills generally consist of native silty clays which were used to bring low areas to grade. Fine to medium grained sand comprises some of the fill which was placed around buried pipelines. In many locations the natural sediments above bedrock may have been completely replaced by fill material.

Bedrock beneath the Base consists of gray shales interbedded with thin limestone beds. Many of the shales contained stringers of limestone and sandstone. Figure 4-2 is a geologic cross section of the Base which illustrates the relationship between bedrock and the overlying deposits. Boring logs from each of the borings and wells completed on the Base are provided in Appendix F.

4.3. SITE GROUNDWATER CONDITIONS

4.3.1 Groundwater in Unconsolidated Materials

Groundwater is found within the unconsolidated surficial materials at shallow (4-12 feet) depths. Figure 4-3 shows the relationship of subsurface conditions to the construction of monitoring wells within the unconsolidated deposits. The groundwater elevation data presented in Table 3-4 has been used to prepare the water table map given in Figure 4-4. Water table contours are prepared by interpolating between points of known elevation. Horizontal flow at the water table is perpendicular to the contours of the water table surface. Flow across the site in the surficial sediments is dominantly from the southeast to the northwest toward the unnamed tributary to Shungunuga Creek which flows along the northwest boundary of the Base. A localized mounding of groundwater is apparent in the vicinity of well SW-2. The reason for this mound is unclear but may be related to the presence of fill materials in this area as noted in the more permeable fill material rather than migrating through the natural soils and thus form a groundwater mound.

In addition to flow through the natural materials, the construction of sewers and pipelines in the sediments has provided a manmade conduit for groundwater flow, especially where sand has been used as backfill. Freeze and Cherry, 1979, state that typical hydraulic conductivities in medium sand range from 1 to 10^{-4} cm/sec whereas in clay, hydraulic conductivities usually range from 10^{-4} to 10^{-9} cm/sec. Translated to groundwater velocities, the median velocity in sand is about 310 feet/year and in clay is .016 feet/year. Therefore, flow through sandy fill areas will be more rapid than through the natural clayey materials and follow the direction of the pipeline grade in much the same manner that a French drain operates. These "drains" can exert a strong influence on localized groundwater flow through the natural clays in their vicinity.

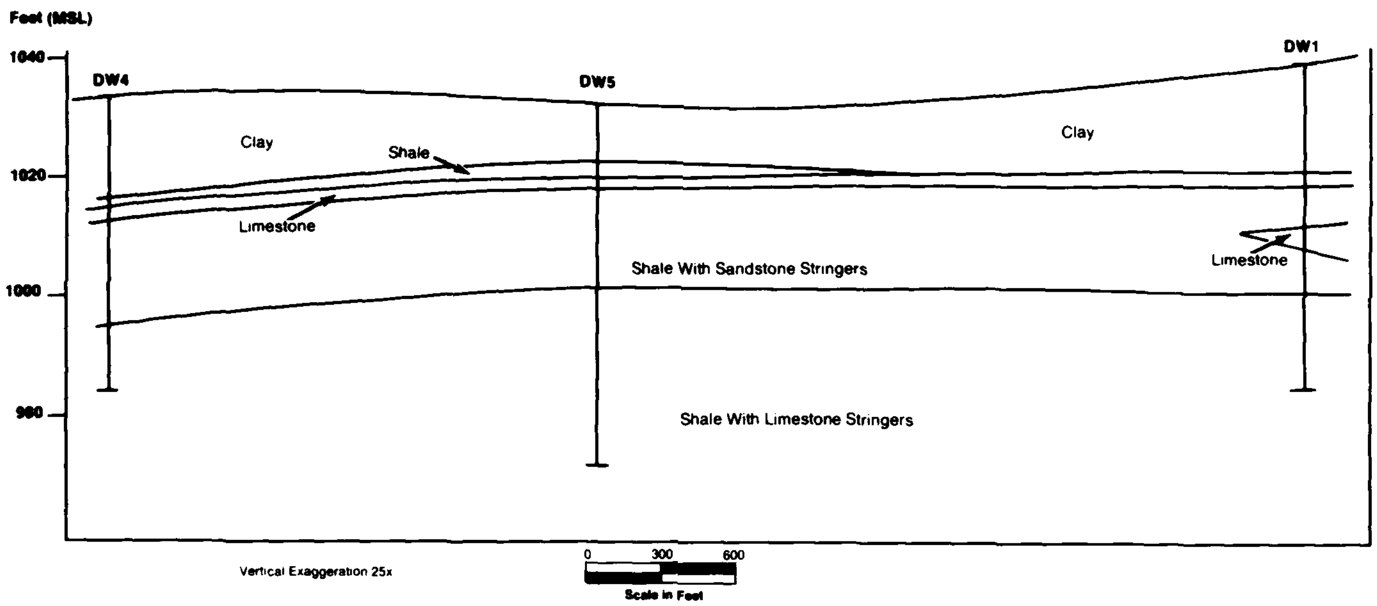


FIGURE 4-2 GEOLOGIC CROSS-SECTION, FORBES FIELD AIR NATIONAL GUARD BASE

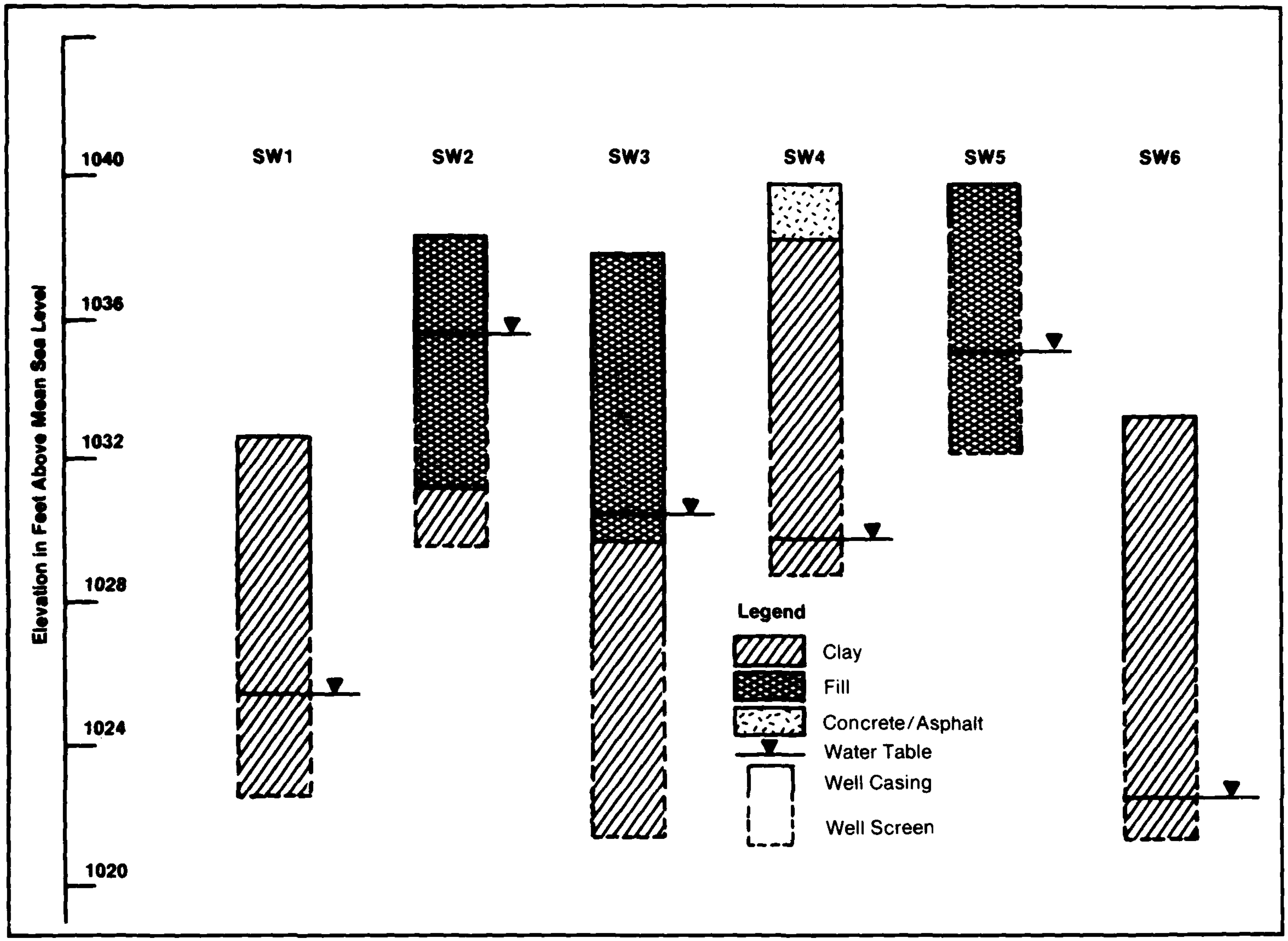
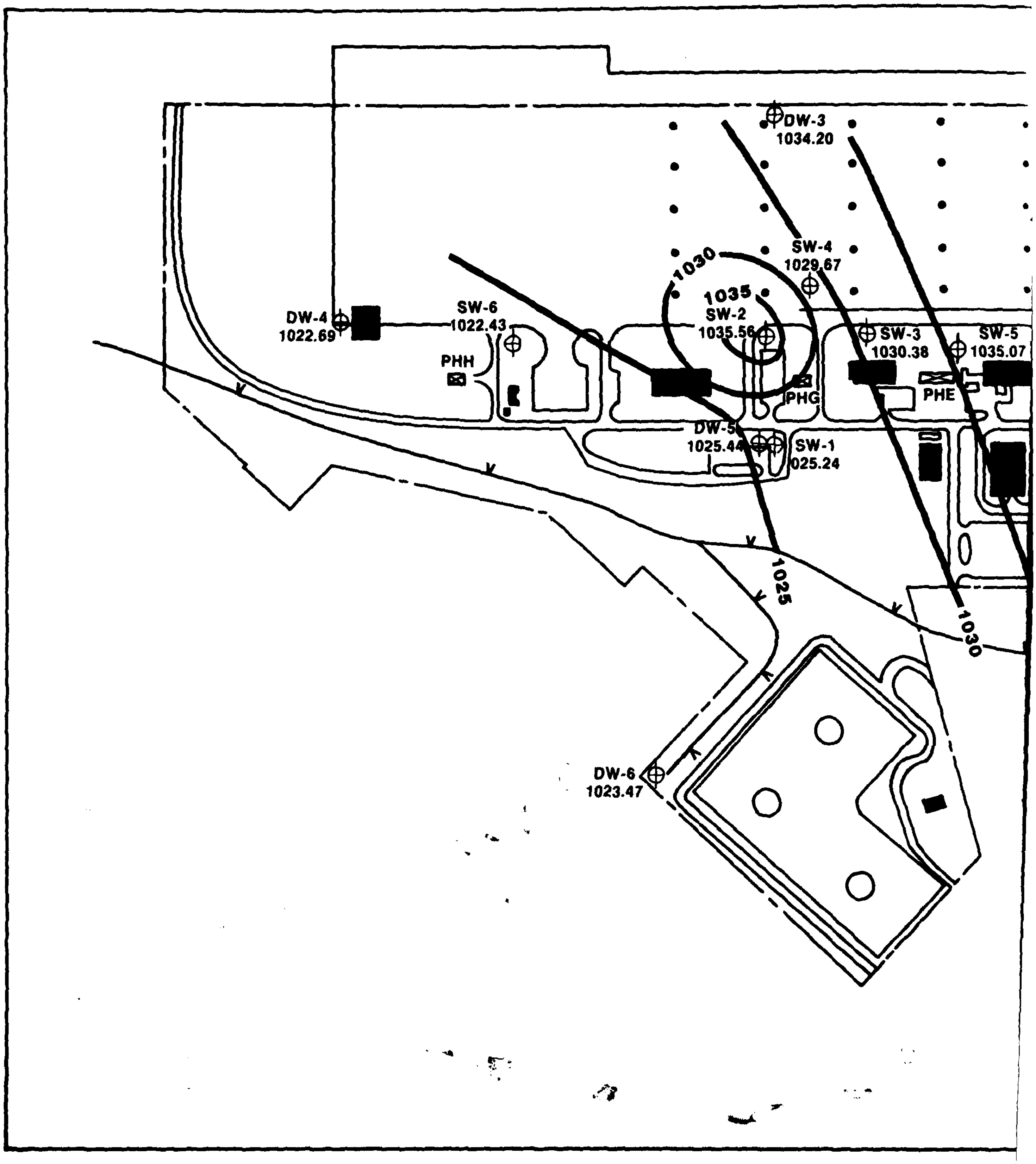


FIGURE 4-3 SCHEMATIC CROSS SECTIONS OF SHALLOW MONITORING WELLS, FORBES AIR NATIONAL GUARD FIELD



DW-3
1034.20
SW-4
1029.67
1030
1035
SW-2
1035.56
DW-4
1022.69
SW-6
1022.43
PHH
PHG
SW-3
1030.38
SW-5
1035.07
PHE
DW-5
1025.44
SW-1
025.24
1025
1030
DW-6
1023.47

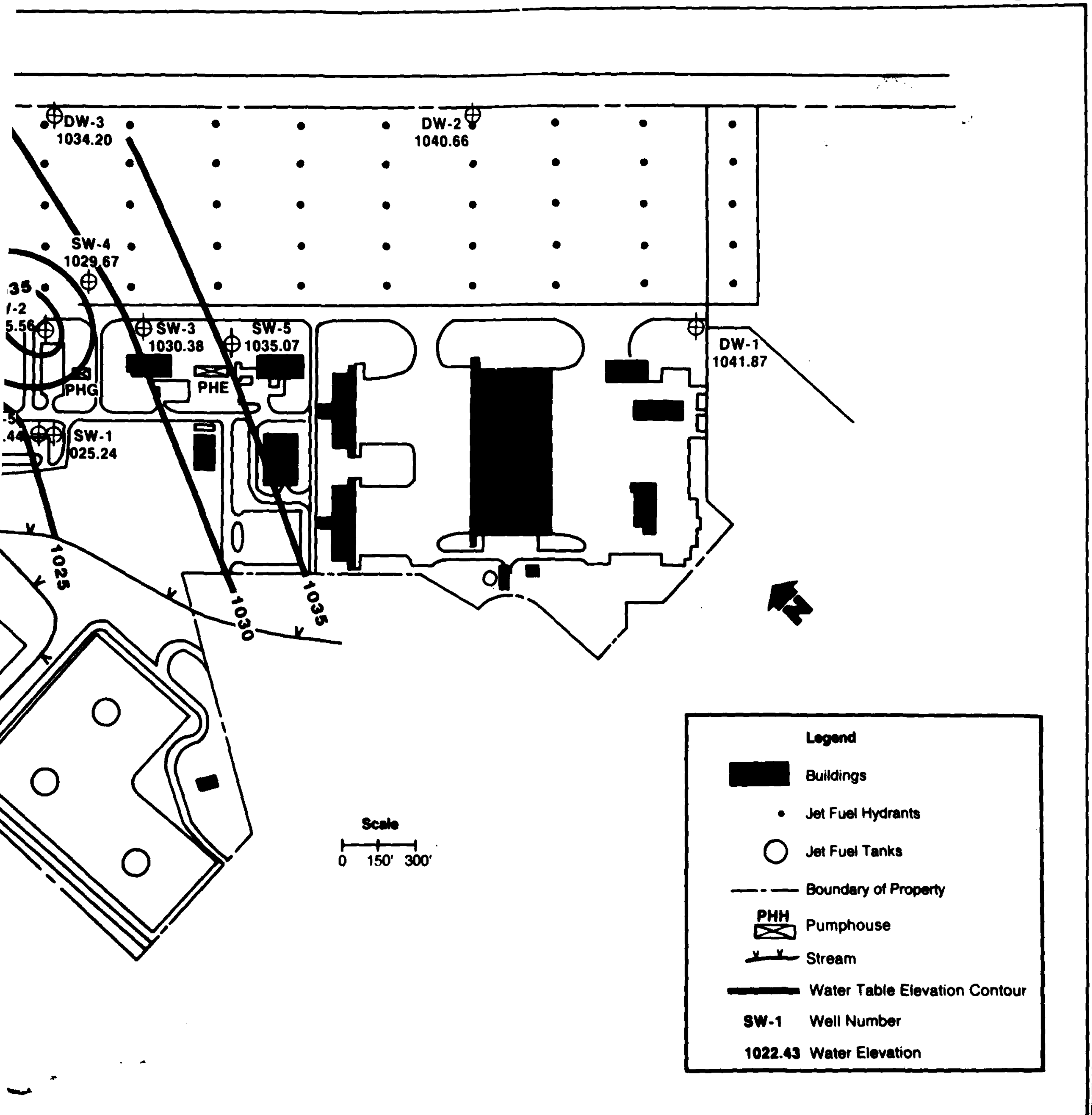


FIGURE 4-4 WATER TABLE CONFIGURATION SHALLOW MONITORING WELLS FEBRUARY 4, 1985

4.3.2 Groundwater in Bedrock

Groundwater in the bedrock system is found under semi-confined conditions. Figure 4-5 shows the relationship of subsurface conditions to the construction of monitoring wells in the bedrock. Figure 4-6 is a piezometric head contour map of the bedrock flow system. Flow is generally from east to west with a component of flow toward the southwest on the north end of the Base and toward the northwest near the bulk fuel storage tanks. In each case flow is generally toward the creek on the northwest boundary of the Base.

Water in bedrock appears to be confined by the overlying clays and by shale beds within the system but are hydraulically connected to groundwater in the unconsolidated materials, especially where construction activities have penetrated bedrock or removed overburden (i.e., storm sewers).

4.3.3 Groundwater Flow Velocity

Average linear flow velocities for groundwater at the water table can be estimated using the following relationship:

$$V=\frac{Ki}{n}$$

where: V = Velocity of flow
K = Coefficient of permeability
i = Hydraulic gradient (vertical or horizontal)
n = Porosity

Permeabilities, estimated from baildown recovery tests, are shown in Table 4-2. These tests measure the rate of recovery of the water level in a well after an instantaneous withdrawal. Because the wells penetrate materials of varying permeability, the test results represent an averaged permeability of the strata open to the well. The test results for wells open only to unconsolidated deposits ranged from 8×10^{-4} cm/sec to 3×10^{-5} cm/sec.

Test results for wells open only to bedrock were 1×10^{-5} cm/sec and 2×10^{-6} cm/sec. In this situation, the baildown test averages the relatively higher permeabilities of the fractured and weathered zones with relatively lower permeabilities of unfractured zones. The values used to

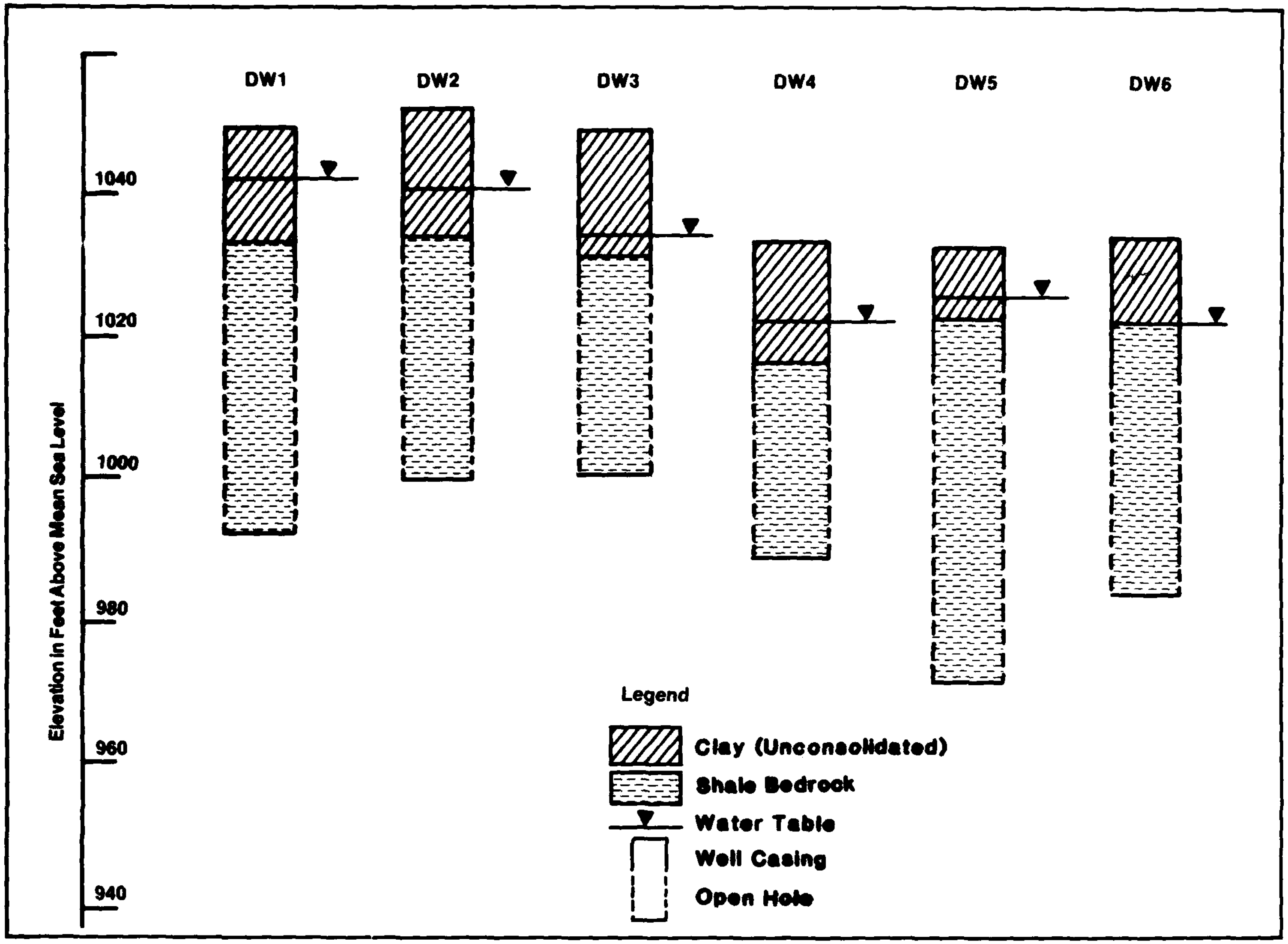
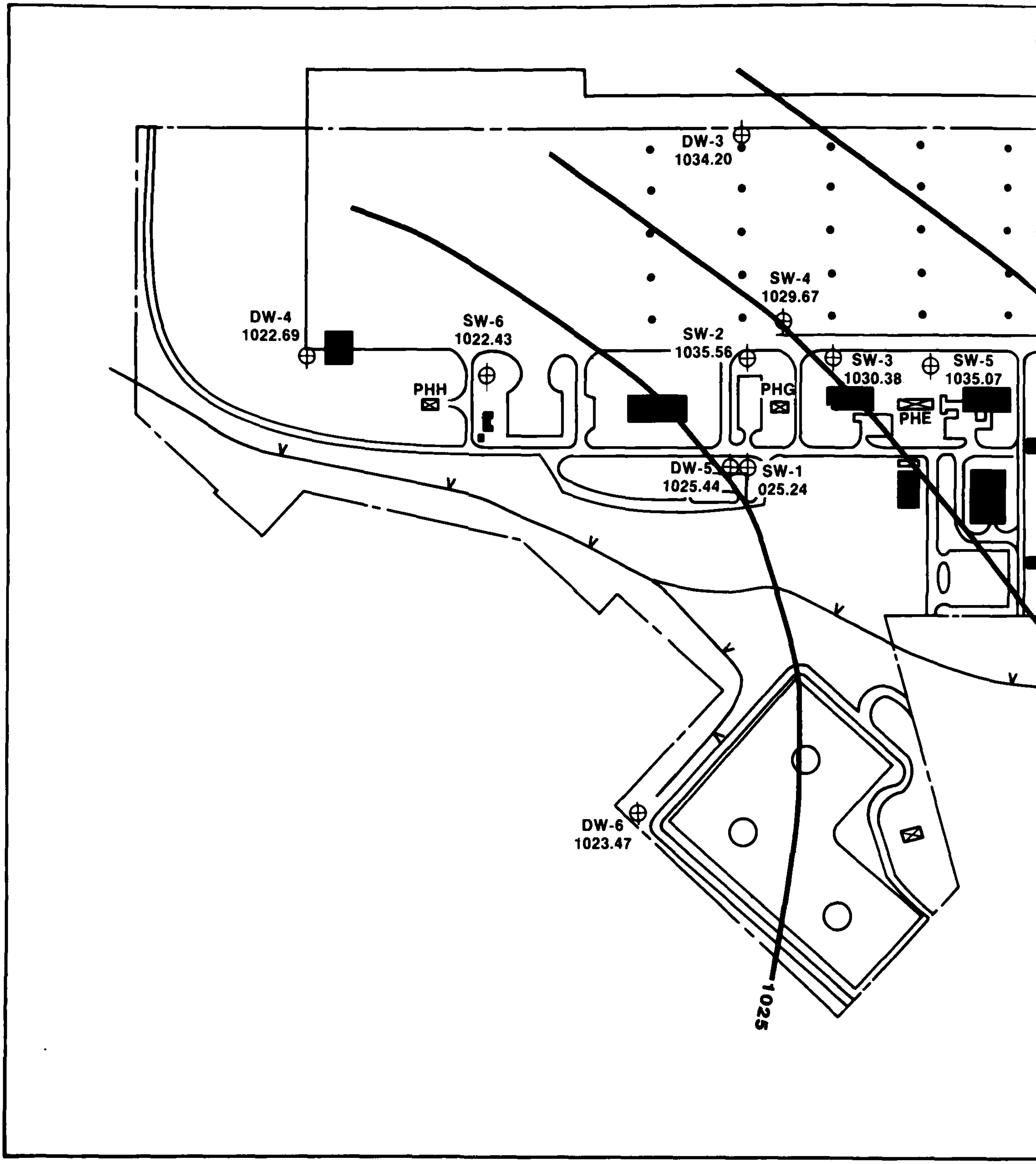


FIGURE 4-5 SCHEMATIC CROSS SECTIONS OF DEEP MONITORING WELLS, FORBES AIR NATIONAL GUARD FIELD



DW-3
1034.20
SW-4
1029.67
DW-4
1022.69
SW-6
1022.43
SW-2
1035.56
SW-3
1030.38
SW-5
1035.07
PHH
PHG
PHE
DW-5
1025.44
SW-1
025.24
DW-6
1023.47
1025

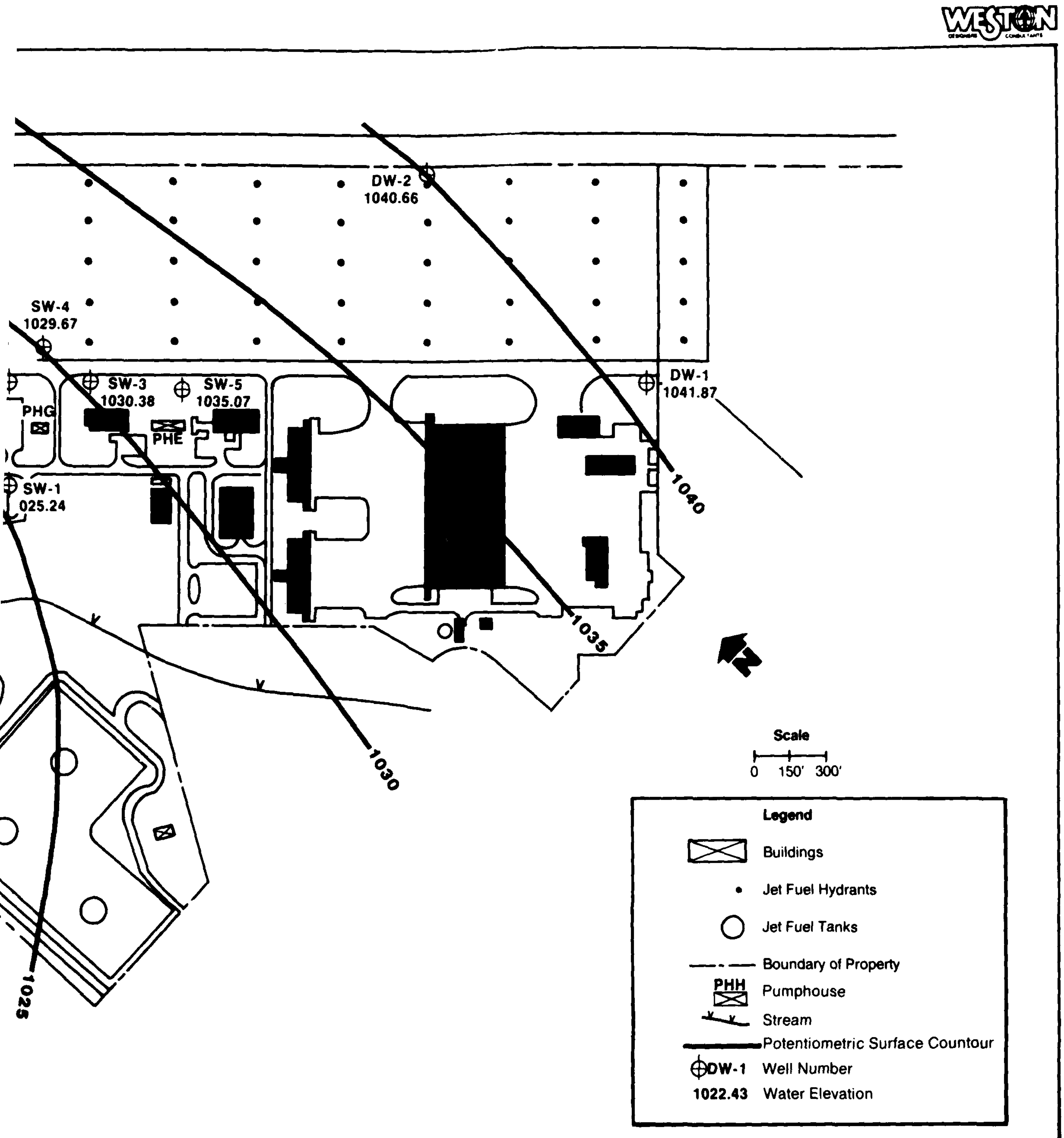


FIGURE 4-6 MONITORING WELL LOCATIONS

2

TABLE 4-2

SUMMARY OF PERMEABILITIES FROM BAILDOWN TESTS
FORBES FIELD AIR NATIONAL GUARD BASE
TOPEKA, KANSAS

Monitoring Well Number	K (ft/min)	K (cm/sec)	K (ft/day)	Aquifer Portions Tested
DW-1	4.174×10^{-6}	2.12×10^{-6}	6.01×10^{-3}	Rock
DW-5	2.313×10^{-5}	1.18×10^{-5}	3.33×10^{-2}	Rock
SW-1	6.109×10^{-5}	3.10×10^{-5}	8.80×10^{-2}	Soil
SW-2	5.071×10^{-5}	2.58×10^{-5}	7.3×10^{-2}	Soil
SW-3	4.826×10^{-4}	2.45×10^{-4}	.69	Soil
SW-6	1.602×10^{-3}	8.14×10^{-4}	2.31	Soil

estimate flow velocities will be the high and low values obtained in both the unconsolidated and bedrock formation wells.

Horizontal hydraulic gradients are equal to the slope of the water table surface. Gradients calculated on the Base ranged from 0.006 ft/ft between DW-2 and DW-5 in the bedrock, and 0.012 ft/ft between SW-5 and SW-1 in the unconsolidated deposits. Porosities for soil and limestone, estimated from tables published in the literature (Freeze and Cherry, 1979) are 40 percent and 20 percent, respectively.

Estimated Horizontal Velocities

- Bedrock - Maximum Velocity

  $K = 3 \times 10^{-2}$ ft/day; $i = 0.006$; $n = 0.20$
  $v = 0.0009$ ft/day or 0.3 ft/year

- Bedrock - Minimum Velocity

  $K = 6 \times 10^{-3}$ ft/day; $i = 0.006$; $n = 0.20$
  $v = 0.00018$ ft/day or 0.07 ft/year

- Unconsolidated - Maximum Velocity

  $K = 2$ ft/day; $i = 0.012$; $n = 0.40$
  $v = 0.06$ ft/day or 22 ft/year

- Unconsolidated - Minimum Velocity

  $K = 8 \times 10^{-2}$ ft/day; $i = 0.012$; $n = 0.40$
  $v = 0.002$ ft/day or 0.9 ft/year

Comparison of these estimates indicates that maximum and minimum velocities vary by about one order of a magnitude between materials. This variation in flow velocities suggests the existence of two separate flow systems rather than a single interconnected flow system. Groundwater in the unconsolidated deposits above bedrock is more mobile than water in the bedrock system.

It can also be assumed that groundwater flow velocities are likely to be substantially higher in sandier backfill materials around pipelines. This is clearly evidenced by the short time period between when a fuel leak occurred and when it was observed. Consequently, velocities for contaminant movement are likely to be higher than those calculated above if the pipeline trenches are migration pathways.

The vertical gradient between the unconsolidated and bedrock flow systems was determined between wells DW-5 and SW-1. The vertical gradient at this location was 0.002 ft/ft in an upward direction. Thus, vertical groundwater flow at this location is from the bedrock into the overlying deposits, and any contaminants present in the unconsolidated materials would tend not to migrate vertically into the bedrock zone.

4.4 ANALYTICAL LABORATORY RESULTS

4.4.1 Soil Analyses

As discussed previously, soil samples collected during drilling and sampling were screened using the OVA and HNu field instrumentation for the potential presence of organic vapors. A total of ten representative soil samples, which exhibited positive field instrumentation response, were selected for laboratory analysis for oil and grease. The sample locations selected, OVA and HNu meter responses recorded in the field and analytical results are summarized in Table 4-3.

The analytical data indicates concentrations of oil and grease typically in the 25 to 50 ppm range at the sampling locations. The oil and grease concentrations were substantially higher at Boring B-10 (adjacent to fueling hydrant 8-A) and SW-5 (adjacent to the intersection of the storm sewer and fuel pipeline from pumphouse E) where concentrations were reported of 686 ppm and 829 ppm, respectively. Fuel hydrant 8-A is a known lcoation of fuel leakage and well SW-5 encountered a thin floating phase of fuel.

The data in Table 4-3 would suggest that OVA meter readings alone are not a reliable indicator of the presence of JP-4 in the soil. The OVA will also detect naturally occurring methane from decomposition of organic matter which was noted in many of the boring logs. The HNu, however, shows good agreement between a positive instrument response and high oil and grease concentrations (methane cannot be detected by the HNu using a 10.2 eV lamp). Review of the boring logs also shows positive HNu meter responses at Boring B-7 (8.2 to 13.2 feet), located between laterals 3 and 4, possibly suggesting the presence of oil and grease there.

Given the large quantities of fuel handled at the Base, it may not be unreasonable to suspect low concentrations of oil and grease (i.e., JP-4) in the soil under the fueling ramp and fuel storage/handling areas. High concentrations of oil and grease in soil are documented in Table 4-3 in areas in relatively close proximity to known fuel leak locations and/or migration pathways. The significance of these data will be a function of the specific organic compounds which comprise the oil and grease concentration values.

TABLE 4-3

SOIL SAMPLING ANALYTICAL RESULTS

Boring Location	Sample Number	Depth (ft)	Field OVA Reading (ppm)	Room OVA Reading (ppm)	Field HNu Reading (ppm)	Room HNu Reading (ppm)	Oil and Grease Conc. (mg/kg)
B-2	S-3	8-13	0	7.2	0	5	51
B-3	S-2	5-8	65	4.2	0	0	50
B-4	S-1	1.7-6.7	55	4.2	0	11	36
B-9	S-3	8-12.7	0	6	0	5	25
B-10	S-1	1-4	10	100	4	300	686
SW-1	S-2	3-8	3	3.5	0	4	38
SW-3	S-4	13-16.5	0	7	0	2	38
SW-4	S-1	1.7-3.2	30	700	0	4	30
SW-4	S-3	8.2-11	100	7	0	4	31
SW-5	S-2	3-7.7	500	1000+	400	200	829

NOTE: Samples for B-2, B-9 and SW-3 exhibited positive OVA and HNu responses when the samples were later warmed to room temperature.

4.4.2 Groundwater Quality Analyses

Oil and grease by Infrared (Method 4132) was chosen by OEHL as an indicator parameter to be used to indicate contamination by JP-4. This method is applicable to measurement of most light petroleum fuels, although loss of about half of any gasoline present during the extraction manipulations can be expected. The results of the oil and grease analyses performed on samples collected from each of the monitoring wells are presented in Table 4-4.

Nine of the twelve water samples collected from the monitoring wells contained oil and grease at concentrations above the detection limit of 0.10 mg/l, while the remaining three samples had no detectable oil and grease.

Concentrations of oil and grease range from a high of 3,970 mg/l in well SW-5 to below detection limits in wells DW-2, DW-3, and DW-4. Those wells finished in the unconsolidated materials above bedrock generally show greater concentrations than those cased into competent rock.

Monitoring wells DW-2, DW-3, and DW-4 are all located upgradient or to the side of suspected source areas and are not contaminated with oil and grease. However, DW-1 is located upgradient of known source areas and was found to contain 0.71 mg/l oil and grease. It is suspected that DW-1 is being affected by potential sources located off the present KSANG property.

Monitoring wells SW-2 and SW-3 were placed adjacent to the fuel distribution lines leading to laterals 7 and 8, respectively. These locations were selected in order to evaluate the presence of JP-4 in the groundwater in the vicinity of known leaks. Well SW-4 was located between laterals 7 and 8 to evaluate migration of contaminants between known source areas. Oil and grease was detected in groundwater at all of these locations.

The location of well SW-5 was chosen to evaluate the presence of JP-4 at the intersection of fuel distribution lines from pumphouse E and the storm sewer system. A floating layer of fuel 0.2 feet thick was found in well SW-5. Monitoring well SW-6 was placed along the storm sewer at the north end of the Base to evaluate whether the contamination extended the full length of the storm sewer system. While no free floating layer of fuel was found in well SW-6, the oil and grease concentration in this well was found to be slightly elevated.

TABLE 4-4

SUMMARY OF WATER QUALITY ANALYTICAL RESULTS

Well	Oil and Grease (mg/l)
SW-1	1.09
SW-1 (Duplicate)	3.27
SW-2	1.75
SW-3	.23
SW-4	.45
SW-5	3970
SW-6	2.03
DW-1	.71
DW-2	<.10
DW-3	<.10
DW-4	<.10
DW-5	1.39
DW-6	.17
Detection Limit	.10
Taste and Odor Threshold	.01

Monitoring wells DW-5 and SW-1 were located downgradient of the known source areas to evaluate whether contaminants have migrated through the bedrock and unconsolidated flow systems toward the northwest. Well DW-5 showed the highest concentration of oil and grease of any of the bedrock monitoring wells. The concentration of oil and grease in well SW-1 was also slightly elevated. The existence of oil and grease in both wells DW-5 and SW-1 indicates that contamination is entering the bedrock flow system as well as the unconsolidated system. Introduction of fuel to the bedrock probably occurs where Base activities (sewer and pipeline construction) have removed the overlying deposits, and the upward flow gradient would be negated by direct hydraulic connection of the shallow and deep flow systems.

Well DW-6 was located at the west corner of the bulk fuel storage area to test for possible contamination in that area. Analytical results show that oil and grease is present at low levels in the bedrock flow system at that location. The source of this contamination is uncertain but is probably related to the storage facilities or dilution of contaminants derived upgradient of the Base.

The above data suggest that oil and grease related compounds are moving to the northwest off the Base property at low concentration. Further dilution and dispersion can be expected to occur as the migration distance increases. The significance of this off-site migration will be dependent on the specific organic compounds which comprise the oil and grease concentrations reported.

4.5 SIGNIFICANCE OF CONTAMINANT MIGRATION

The principal objective of this study was to determine whether past operations have resulted in environmental degradation. Indications from sampling show that releases to the environment have occurred. The consequence of these releases are that fuel is migrating from the Base through the groundwater toward the creek at the northwest edge of the property. Also, contaminants are migrating on-site from the east in the lower aquifer as evidenced by contamination in upgradient well DW-1. The source of contamination is most likely from past breaks of laterals off-site as well as a fire training area which was located to the east.

Contamination in groundwater may reach the creek by one of two methods. It may migrate through the natural materials with groundwater flow until it reaches the creek, or alternatively, contaminants may migrate along the disturbed areas in the soil (where pipelines have been constructed) at rates higher than through natural materials. The data collected in this study indicates that both of these methods of contaminant transport are in operation. Oil and grease was found in wells located along the storm sewer system as well as in wells downgradient of known source areas. In either case, it is believed that contaminants released from the fuel handling facilities at Forbes Field will migrate to nearby surface waters.

No standards exist for the concentration of oil and grease in groundwater. Oil and grease was found to be in excess of the taste and odor threshold of 0.01 mg/l in nine of the twelve wells installed on Base. The remaining three wells had no detectable oil and grease at 0.10 mg/l, the limit of detection for this study. The conclusions drawn from this information should be evaluated with this understanding.

4.6 CONCLUSIONS

Based on the results of this study at Forbes Field ANGB, the following key conclusions have been drawn:

4.6.1 General Conclusions

- Unconsolidated sediments at the Base consist of clays and silty clays which were apparently weathered from underlying materials. Bedrock consists of shales with interbedded limestones and some sandstone stringers.

- Groundwater beneath Forbes Field ANGB occurs under water table conditions in the unconsolidated sediments above bedrock and under confined conditions within permeable zones of bedrock.

- General groundwater flow is from east to west toward the unnamed tributary to Shungunuga Creek which is located at the northwest edge of the Base.

- In areas where natural unconsolidated materials overlie bedrock, an upward component of flow exists from bedrock into the unconsolidated materials.

4.6.2 Presence of Contaminants

- Concentrations of oil and grease in excess of the taste and odor threshold were found in nine of the twelve groundwater monitoring wells sampled.

- Oil and grease was found in all ten soil samples submitted for chemical analysis.

- A floating layer of fuel 0.20 feet thick was found in shallow monitor well SW-5.

- The presence of oil and grease in deep monitor well DW-1, which is located upgradient of suspected source areas on the Base, indicates the potential that contaminants are migrating onto the Base from other areas.

4.6.3 Migration of Contaminants

- Contaminants may enter the groundwater flow system by percolating through surficial materials or by introduction to the shallow bedrock in locations where overlying materials have been removed. Trenching for construction of sewers and fuel lines has created conduits for migration of contaminants into bedrock and laterally to the storm sewer system. This is evident in well SW-5 where fuel has accumulated in backfill materials surrounding a fuel distrubution line and by past discharges of fuel to the storm sewer system.

- The fate of contaminants migrating from Base facilities in groundwater is to travel laterally toward the tributary to Shungunuga Creek which flows along the western boundaries of the Base. It is not known if contaminants have now reached this point.

4.6.4 Significance of Findings

- The effects on the environment of any contaminants which may leave the Base are unknown at this time. The identity of the specific compounds leaving the Base must be known before this determination can be made.

- The relatively low levels of contamination encountered in the majority of locations tested seems to indicate that much of the fuel released to the environment by the known leaks has been either flushed from the subsurface or cleaned up by base efforts.

- Contaminant levels appear to diminish rapidly with distance from source area. This trend is expected to continue as distance from the source is increased.

SECTION 5

RECOMMENDATIONS

The principal goal of this study at Forbes Field Air National Guard Base was to determine whether or not environmental degradation was occurring as a result of materials handling practices at the installation. The results presented in Section 4 confirm that the groundwater and soils in the immediate area of fuel handling installations have been affected. These preliminary findings require additional verification which is discussed below. These recommendations are intended to evaluate whether contaminants are leaving the Base, and if so, which contaminants and at what concentrations.

The following additional work is recommended for Forbes Field ANGB.

1) An additional round of samples should be taken from existing wells DW-1 through DW-6 and SW-1 through SW-6 to verify the results obtained from the first sampling round. The parameters tested should be expanded to include U.S.EPA Priority Pollutant volatile organic compounds plus xylene.

2) Five additional groundwater monitoring wells should be constructed between Base facilities and the drainage way on the northwest side boundary. Four wells should be installed along the northwest boundary to determine if groundwater quality is being impacted at the downgradient edge of the property. Three of these wells should be completed in the unconsolidated deposits to monitor migration in the upper flow system. The remaining well should be a deep well located to monitor contaminant migration in the bedrock flow system. The fifth well should be installed at the northeast corner of the bulk fuel storage tank farm near the head of the surface water drainage ditch. Samples from these wells should be analyzed for the expanded parameter list.

3) Surface water samples should be collected from three locations in the drainage ditch on the northwest property boundary. One sample should be collected upstream of the bulk fuel storage area. The second sample should be collected mid-way between bulk fuel storage and the storm sewer outfall. The third sample should be collected from the area of the storm sewer outfall. Analysis of these samples should be for the expanded list of analyses.

4) At least one shallow monitoring well should be installed on the eastern edge of the site to monitor contamination possibly migrating on site from the east in the upper aquifer.

5) During collection of the next round of samples, the elevation of the stream bottom should be surveyed to determine whether the stream is recharging the groundwater system.

REFERENCES

Adkison, W.L and Johnson, W.D., 1967, Geology of Shawnee County, Kansas, U.S.G.S. Bulletin 1215-A, 254 pp.

Bouwer, H. and Rice, R.C., 1976, A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells, Water Resources Research, Vol. 12, No. 3, pp. 423-428.

Freeze, R.A. and Cherry, J.A., 1979, Prentice-Hall, Englewood Cliffs, 603 pp.

APPENDIX A

ACRONYMS, DEFINITIONS, NOMENCLATURE AND UNITS OF MEASUREMENT

ANGB	Air National Guard Base
ASTM	American Society for Testing and Materials
Bldg.	Building
CERCLA	Comprehensive Environmental Response Compensation and Liability Act of 1980
cm/s	Centimeters per second
DEQPPM	Defense Environmental Quality Program Policy Memorandum
DoD	Department of Defense
°C	Degrees Centigrade
°F	Degrees Fahrenheit
ft/min	Feet per minute
gpm	Gallons per minute
HARM	Hazard Assessment Rating Method
hr	Hour
in	Inches
IRP	Installation Restoration Program
MS	Master of Science Degree
KSANG	Kansas, Air ational Guard
ug/l	Micrograms per liter (equivalent to parts per billion in water)
umho/cm	Micromhos per centimeter (units of Specific Conductance)
mg/l	Milligrams per liter (equivalent to parts per million in water)
mg/g	Milligrams per gram (equivalent to parts per thousand in soil)
mgd	Million gallons per day
MSL	Mean Sea Level Datum
N	North
No.	Number
O & G	Oil and Grease
OEHL	Occupational and Environmental Health Laboratory

%	Percent
P.G.	Registered Professional Geologist
Ph.D.	Doctor of Philosophy Degree
ppb	parts per billion (equivalent to ug/l in water)
ppm	parts per million (equivalent to mg/l in water)
QA/AC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act of 1976
TAC	Tactical Air Command
USAF	United States Air Force
USEPA	United States Environmental Protection Agency

APPENDIX B

Scope of Work TASK ORDER 0051

25 JUL 1984

GROUND-WATER CONTAMINATION STUDY
FORBES FIELD ANG BASE KS

I. Description of Work

The purpose of this task is to determine if soil and ground-water contamination have resulted from fuel storage, distribution, and use at Forbes Field ANGB KS; to provide estimates of the magnitude and extent of contamination, if present; to identify potential environmental consequences of migrating pollutants; to identify any additional investigations and their attendant costs necessary to identify the magnitude, extent, and direction of movement of discovered contaminants.

Ambient air monitoring of hazardous and/or toxic material, for the protection of contractor and Air Force personnel, shall be accomplished when necessary, especially during the drilling operation.

The presurvey report (mailed under separate cover) incorporated background and description of the facility for this task. To accomplish the survey, the contractor shall take the following steps:

A. General

1. Determine the areal extent of the facility by reviewing available historical and recent aerial photos of the base.

2. A total of 10 soil borings and 12 monitoring wells shall be installed. Maximum depth per soil boring shall be 10 feet. Maximum depth of each bedrock well is 70 feet. Maximum depth of each shallow well is 10 feet.

3. Locations of all soil borings and monitoring wells shall be staked out with a representative from base Civil Engineering to ensure that fuel supply, drainage, and utility lines are not intercepted.

4. Ground-water monitoring wells shall comply with U.S. EPA publication 330/9-81-002 NEIC Manual for Groundwater/Subsurface Investigations at Hazardous Waste Sites, and State of Kansas requirements for monitoring well installation. Only screw type joints shall be used. Glued fittings are not permitted.

5. Wells shall be of sufficient depth to intercept contaminants if they are present. All wells shall be developed, water levels measured, and locations surveyed and recorded on a site map.

6. All water samples shall be analyzed on-site by the contractor for pH, temperature, and specific conductance. Sampling, maximum holding time, and preservation of samples shall comply strictly with the following references: Standard Methods for the Examination of Water and Wastewater, 15th Ed. (1980), pp 3542; ASTM, Section 11, and Methods for Chemical Analysis of Waters and Wastes, EPA Manual 600/4-79-020, pp xiii to xix (1979). All water and soil samples shall be analyzed using minimum detection

levels as specified in items I.B.2.c and I.B.2.e below, and in Attachment 1 to this statement of work.

7. Field data collected for each site shall be plotted and mapped. The magnitude and potential for contaminant flow to receiving streams and ground waters shall be determined or estimated.

B. In addition to items delineated in A above, conduct the following specific actions at Forbes Field ANGB:

1. Inspection of Storm Sewers

a. A maximum of 20 manholes leading to the storm sewer system in the area of suspected fuel leakage shall be entered and inspected for evidence of fuel. The inspection shall consist of both visual observations and testing with a portable Organic Vapor Analyzer (OVA), and an HNU photoionizer (HNU). The contractor shall wear appropriate safety equipment; a KS ANG representative will be present above ground when the contractor enters manholes.

b. A maximum of five stormwater samples shall be collected from the manholes, and screened with the OVA and HNU.

2. Field Investigation

a. A maximum of ten soil borings shall be made to determine if fuel is present in the unconsolidated sediments. Depth per boring shall not exceed ten feet.

(1) One boring shall be located at each of the three pump houses (E, G. and H).

(2) One boring shall be extended through the concrete between laterals 2 and 3; one between laterals 4 and 5; one between laterals 7 and 8; one between fueling hydrants A and B.

(3) The locations of the remaining three borings shall be determined by the contractor in the field.

b. Continuous split-spoon sampling shall be used for sample collection. The OVA and HNU shall be used in the field to detect the presence of organic compounds in the soil samples, and as an aid in selecting representative samples for laboratory analysis.

c. A maximum of ten soil samples shall be chosen for analysis. Each soil sample shall be analyzed for oil and grease by the infrared method, EPA 413.2 (O&G/IR). The detection level required is 100 ug/g.

d. A maximum of 12 ground-water monitoring wells shall be installed.

(1) Six wells (four inch diameter) shall be constructed into the limestone and shale bedrock. PVC casing shall extend to five feet into competent bedrock. Each well shall extend to 30 feet below the water table in

the bedrock. The depth of each well shall not exceed 70 feet. Soil samples shall not be taken during bedrock well construction.

(a) One well shall be installed at each of the following locations: the northwest corner of the site near the storm sewer culvert; the northeast edge of the site at the end of lateral 8; the southeast edge of the site near building 660; the southwest corner of the site near the three 190 series fuel storage tanks.

(b) The location of two wells shall be determined in the field.

(2) Six shallow wells (two inch diameter) shall be constructed into the silty clays which overlie bedrock, and into the backfill materials which surround buried pipelines. The depth of each well shall not exceed ten feet. The contractor shall perform split-spoon sampling during construction of shallow wells. Wells shall be constructed of PVC casing and screen. Screen length shall be five feet in each well. The bottom three feet of each screen shall be set below the saturated zone and the top two feet shall extend two feet above the saturated zone.

(a) Two wells shall be located in backfill materials around the storm sewer which drains the areas around laterals 7 and 8, on the west side of the fueling pad.

(b) One well shall be located in undisturbed silty clays between laterals 7 and 8.

(c) The location of the remaining three shallow wells shall be determined in the field.

(3) Elevations of all wells shall be surveyed BY THE CONTRACTOR to an error of less than 0.1 foot.

(4) Following well installation, field baildown tests shall be performed on six wells (determined by the contractor) as a test of subsurface permeability.

(5) Prior to ground-water sampling, the depth to ground water shall be measured. If fuel is present in the well, the thickness of the fuel layer on the water table shall also be measured.

e. Collect one ground-water sample from each well (a total of 12 samples). Analyze each ground-water sample for O&G/IR. The detection level required is 0.1 mg/L.

C. Well and Borehole Cleanup

All well and boring area drill cuttings shall be removed and the general area cleaned following the completion of each well and boring. Only those drill cuttings suspected of being a hazardous waste (based on discoloration, odor, or organic vapor detection instrument) shall be properly containerized (according to local civil engineering office requirements) by the contractor for eventual government disposal. The suspected hazardous waste shall be tested (maximum of five samples) by the contractor for EP Toxicity and Ignitability. The contractor is not responsible for ultimate disposal of the drill cuttings. Disposal will be conducted by base personnel.

D. Data Review

Results of sampling and analysis shall be tabulated and incorporated into the monthly R&D Status Reports and forwarded to the USAF OEHL for review as soon as they become available, as specified in Item VI below.

E. Reporting

1. A draft report delineating procedures used and all findings of this field investigation shall be prepared and forwarded to USAF OEHL/TS, as specified in Item VI below, for Air Force review and comment. The report shall follow the USAF OEHL supplied format (mailed under separate cover). The report shall include:

a. A discussion of the regional hydrogeology.

b. Results of the storm sewer inspection.

c. Logs of monitoring wells and borings, soil cross sections, and ground-water level data.

d. Water and soil quality analyses results.

e. Mapped and contoured data to indicate direction of potential fuel migration.

f. Estimates of the rates of movement of ground water and fuel (if present), and probable travel paths.

g. A discussion on the potential for off-site migration of fuel (if present), and probable receiving waters.

h. Field and laboratory quality assurance information.

2. Where survey data are insufficient to properly determine or estimate the magnitude and direction of movement of discovered contaminants, fully justified, specific recommendations shall be made for additional efforts required to properly evaluate fuel migration.

F. Cost Estimates

The contractor shall provide cost estimates for all additional work recommended to permit proper determination of fuel presence and extent of migration. The recommendations shall include all efforts required to determine the magnitude and direction of movement of discovered fuel, along with an estimate of the time required to accomplish the proposed effort. This information shall be provided in a separately bound appendix to the draft final report.

G. Meetings

The contractor's project leader shall attend one meeting with Air Force headquarters and regulatory agency personnel, to take place at a time to be specified by the USAF OEHL. The meeting shall take place at Forbes Field ANGB, for a duration of one day (eight hours).

II. Site Location and Dates

Forbes Field ANGB
Topeka KS
Dates to be established

III. Base Support: None

IV. Government Furnished Property: None

V. Government Points of Contact:

1. 1Lt Dulcie A. Weisman
USAF OEHL/ECQ
Brooks AFB TX 78235
(512) 536-3305
AV 240-3305

2. 1Lt David P. Gibson
USAF OEHL/ECQ
Brooks AFB TX 78235
(512) 536-3305
AV 240-3305

3. Lt Col Kenneth L. Simpson
190th ARG/DE
Forbes Field ANGB KS 66620
(913) 862-~~4827~~-1234, x 4827
AV 720-4827

4. Lt Col Michael C. Washeleski
ANGSC/SG
Andrews AFB MD 20331
(301) 981-5926
AV 858-5926

VI. In addition to sequence numbers 1*, 5 and 11, which are listed in Attachment 1 to the contract, and are applicable to all contracts, the sequence number listed below is applicable. Also shown is date applicable to this order:

*Forward one copy of the R&D Status Report to all government POCs identified in Section V.

Sequence No.	Block 10	Block 11	Block 12	Block 13	Block 14
4	OTIME	84 DEC 28	85 JAN 18	85 Mar 18	*

*Fifteen copies of the draft final report shall be forwarded to USAF OEHL/TS, for AF review and comment. One copy of the final report shall be forwarded to the USAF OEHL project officer to verify that comments have been incorporated. Upon acceptance by the USAF OEHL, twenty-five copies of the final report, plus the camera-ready copy, shall be forwarded to USAF OEHL/TS

	Detection Level	No. Sample
O&G/IR (EPA method 413.2)	0.1 mg/L (waters); 100 ug/g (soil)	12w, 10s

w = water
s = soil

If drill cuttings are suspected of being hazardous material, five samples shall be tested for EP Toxicity and Ignitability.

Atch 1

APPENDIX C

PROFESSIONAL PROFILES OF KEY PERSONNEL

Peter J. Marks

Fields of Competence

Project management; environmental analytical laboratory analysis; hazardous waste, groundwater and soil contamination; source emissions/ambient air sampling. wastewater treatment; biological monitoring methods; and environmental engineering.

Experience Summary

Eighteen years in Environmental Laboratory and Environmental Engineering as Project Scientist, Project Engineer, Process Development Supervisor, and Manager of Environmental Laboratory with WESTON. Experience in analytical laboratory, wastewater surveys, hazardous waste, groundwater and soil contamination, DoD-specific wastes, stream surveys, process development studies, and source emission and ambient air testing. In-depth experience in pulp and paper, steel, organic chemicals, pharmaceutical, glass, petroleum, petrochemical, metal plating, food industries and DoD.

Applied research on a number of advanced wastewater treatment projects funded by Federal EPA.

Credentials

B.S., Biology—Franklin and Marshall College (1963)

M.S., Environmental Engineering and Science—Drexel University (1965)

American Society for Testing and Materials

Water Pollution Control Federation

Water Pollution Control Association of Pennsylvania

Employment History

1965-Present	WESTON
1963-1964	Lancaster County General Hospital Research Laboratory for Analytical Methods Development

Key Projects

USAF/OEHL Brooks AFB. Program Manager for this three-year BOA contract provides technical support in environmental engineering surveys, wastewater characterization programs, geological investigations, hydrogeological studies, landfill leachate monitoring and landfill siting investigations, bioassay studies, wastewater and hazardous waste treatability studies, and laboratory testing and/or field investigations of environmental instrumentation/equipment. Collection, analysis, and reporting of contaminants present in water and wastewater samples in support of Air Force Environmental Health Programs.

United States Army Toxic and Hazardous Materials Agency (USATHAMA), Aberdeen Proving Ground, Maryland. Program Manager for three-year basic ordering agreement contract to provide research and development for technology in support of the DOD Installation Restoration Program. The objective of the Program is to identify and develop treatment methods/technology for containment and/or remedial action. Technology development for remedial action is to include groundwater, soils, sediments, and sludges.

Confidential Client, Ohio. Project Manager of an on-going contract to conduct corporate environmental testing and special projects at client's U.S. and overseas plants. WESTON must be able to assign up to four professionals to a project within a two week notice.

Confidential Client (Inorganic and Organic Chemicals). Product Manager of a current contract to conduct wastewater sampling and analysis of plant effluent for priority pollutants. The project also includes a wastewater treatability study to evaluate a number of process alternatives for removal of priority pollutants from the present effluent.

Confidential Client, Utah. Technical Project Manager for in-depth wastewater survey, in-plant study, treatability study, and concept engineering study in support of the client's objectives to meet 1983 effluent limitations. WESTON had two project engineers, two chemists, five technicians and an operating laboratory in the field. Field effort is six months duration.

Professional Profile

In conjunction with University of Delaware College, WESTON analyzed more than 500 biological and marine sediment samples for eleven constituent trace metals as part of a program to identify and trace the migration of metals from ocean dumping of sludges on the continental shelf off the coast of the State of Delaware, acted as Technical Project Manager.

Project Manager in charge of a wastewater analysis and biological treatability project for industrial client for the identification and degradation of six pesticide-containing wastewaters.

U.S. EPA Environmental Monitoring and Support Laboratory. Multi-year contract to provide reference laboratory analysis on QA/QC samples produced from the EPA Analytical Laboratory QA/QC program.

Publications

"*Microbiological Inhibition Testing Procedure*," Biological Methods for the Assessment of Water Quality, A.S.T.M. Publication STP 528.

"Heat Treatment of Waste Activated Sludge" (with V.T. Stack).

"Biological Monitoring in Activated Sludge Treatment Process," a joint paper with Stover/Woldman.

Frederick Bopp III, Ph.D., P.G.

Registration

Registered Professional Geologist in the State of Indiana

Fields of Competence

Groundwater resources evaluation; hydrogeologic evaluation of sanitary landfills and other waste disposal sites; detection and abatement of groundwater pollution; digital modeling of groundwater flow and solute transport; statistical analysis of geological and geochemical data; geochemical prospecting; estuarine geology and geochemistry; trace metal and aqueous geochemistry.

Experience Summary

Seven years experience in hydrogeology and geochemistry, involving such activities as: assessment of subsurface water and soil contamination; development of contamination profiles; evaluation of remediation actions for groundwater quality restoration; quantitative chemical analysis of water and soil; ore assay and ore body evaluation; drilling supervisor; hydrogeologic assessment; pollution detection and abatement; estuarine pollution analysis; application of flow and solute transport computer models; computer programming; project management; teaching environmental geology and geochemistry.

Credentials

B.A., Geology—Brown University (1966)

M.S., Geology—University of Delaware (1973)

Ph.D., Geology—University of Delaware (1979)

Sigma Xi, The Scientific Research Society of North America

Geological Society of America, Hydrology Division

National Water Well Association, Technical Division

American Association for the Advancement of Science

Estuarine Research Federation: Atlantic Estuarine Research Society

Employment History

1979-Present	WESTON
1977-1979	U.S. Army Corps of Engineers Waterways Experiment Station
1976-1977	University of South Florida Department of Geology
1970-1976	University of Delaware Department of Geology
1974-1976	Earth Quest Associates President and Principal Partner
1974 (Summer)	WESTON
1966-1970	United States Navy Commissioned Officer

Key Projects

Project manager on seven task orders for environmental assessment services at United States Air Force facilities in nine states.

Task manager for a Superfund site evaluation in Ohio.

Site manager for drum recovery operations in Pennsylvania and New Jersey.

Project manager for site assessments of oil and fuel spills in four states.

Project manager for closure plan development at a hazardous waste landfill in New Jersey.

Definition and abatement of groundwater contamination from chemical manufacturing in Delaware.

Flow and solute transport digital model of a heavily-pumped regional aquifer in southern New Jersey.

Definition and abatement of groundwater contamination from chemical manufacturing in the Denver area.

Hydrogeologic impact assessment of on-land dredge spoil disposal in coastal North Carolina.

Geochemical prospecting and ore body analysis in Arizona.

Professional Profile

Definition and abatement of groundwater contamination from a hazardous waste site in northern New England.

Definition and abatement of groundwater contamination from plating and foundry wastes in eastern Pennsylvania.

Operational test and evaluation of new naval mine ordinances in southern Florida.

Publications

"Metals in Estuarine Sediments: Factor Analysis and Its Environmental Significance". *Science*, 214 (1981): 441-443.

"The Remobilization of Trace Metals from Suspended Sediments Entering the Delaware Estuary". Presented at the 27th Annual Meeting, Southeastern Section, Geological Society of America, Chattanooga, Tennessee, April 1978.

"Trace Metals in Delaware Bay Sediments and Oysters". Presented at the International Conference on Heavy Metals in the Environment, Toronto, Canada, October 1975.

Robert J. Karnauskas, P.G.

Registration

Certified Professional Geological Scientist and Certified Professional Geologist in the state of Indiana.

Fields of Competence

Geological aspects relating to locational and design considerations of solid and hazardous waste disposal facilities; evaluation of organic and inorganic groundwater contamination problems; aquifer restoration and rehabilitation; land disposal of municipal and industrial wastewaters and sludges; physical and chemical characterization of industrial waste materials to assess groundwater contamination potential; groundwater modeling; evaluation of hydrogeologic aspects of construction problems; and NPDES permit program coordination.

Experience Summary

Six years of professional experience in consulting environmental engineering. Project assignments have blanketed a broad range of industries including pulp and paper, solvent processing and recycling, electric power utilities, food processing, private and public solid waste operations, foundries, and agriculture. Experience includes the hydrogeologic evaluation of a wide variety of subsurface environments and groundwater contamination concerns. Research experience has included the evaluation of leachate characteristics from municipal and industrial wastes as well as the development of methods for assessing leakage rates from industrial wastewater lagoons.

Credentials

B.A., Geology and Geophysics—University of Wisconsin, Madison (1975)

M.S., Geology (Hydrogeology)—University of Wisconsin, Madison (1977)

M.S., Water Resources Management—University of Wisconsin, Madison (1977)

University of Wisconsin, Madison—Part-time graduate studies in Business Management (1983)

National Water Well Association, Technical Division

American Institute of Professional Geologists

Employment History

1983-Present	WESTON
1977-1983	Warzyn Engineering Inc.

Key Projects

Project Hydrogeologist and/or Project Manager for several major fly ash disposal facilities for Wisconsin Electric Utilities, including site selection, subsurface feasibility evaluations, technical input to engineering design, construction and groundwater monitoring.

Project Hydrogeologist and Project Manager on a major groundwater contamination study of private water supply wells from cheese manufacturing waste processes. Scope of work included identification, evaluation and mitigation of groundwater contaminant sources.

Project Hydrogeologist for the subsurface evaluation and design of a major county zone of saturation landfill, including expert testimony at regulatory licensing hearings.

Designed a detailed test monitoring area within a large fly ash disposal facility to evaluate leachate quality and quantity generated within and leaving the facility. The test program is designed to compare field results with predicted leachate quality and environmental impacts from laboratory characterization of the ash.

Project Manager on a detailed subsurface investigation evaluating PCB contamination in soils and groundwater.

Project Hydrogeologist and Project Manager investigating the scope and magnitude of solvent contamination in soils and groundwater at a solvent reprocessing facility, including liaison with local and state governmental agencies, and public relations.

Professional Profile

Project Hydrogeologist and Project Manager investigating contamination of a municipal water supply well derived from food processing and canning wastes.

Project Hydrogeologist for a regional groundwater resource evaluation investigating agricultural water use and its effect on process water availability for a Wisconsin paper manufacturer.

Publications

Karnauskas, Robert J. and M. P. Anderson, "Groundwater Lake Relationships and Groundwater Quality in the Sand Plain Province of Wisconsin—Nepco Lake", *Groundwater Journal*, 1978.

Ham, R. K. and R. J. Karnauskas, "Leachate Production from Milled and Unprocessed Refuse", International Solid Waste Association Information Bulletin, 1974.

Karnauskas, R. J., C. E. R. Lawson and M. E. Horn, "The Feasibility of Fly Ash Utilization for FGD Scrubber Sludge Stabilization, Columbia Generating Station, Portage, Wisconsin". Proceedings of Second Annual Conference of Applied Research and Practice on Municipal and Industrial Waste, 1979.

Karnauskas, R. J. and P. J. Huettl, "Land Application of Whey", *Dairy Field*, May and June, 1981.

Walter M. Leis, P.G.

Registration

Registered Professional Geologist in the States of Georgia (No. 440) and Indiana.

Fields of Competence

Detection and abatement of groundwater contamination; design of artificial recharge wells; deep well disposal; simulation of groundwater systems; hydrogeologic evaluation of hazardous waste sites and landfills; practical applications of geophysical surveys to hydrologic systems, site investigations, and borehole geophysical surveys. Geochemical studies of acid mine drainage and hazardous wastes.

Experience Summary

Sixteen years experience as field hydrogeologist, field supervisor, project director, research director. Six years research involving two consecutive projects: 1) application of geophysical techniques in evaluating groundwater supplies in fractured rock terrain in Delaware and Pennsylvania; 2) project director for an artificial recharge and deep well disposal study. Provided consultation for waste disposal and aquifer quality problems for coastal communities.

Developed geochemical sampling techniques for deep mine sampling. Evaluated synthetic and field hydrologic data for deep formulational analysis in coal field projects.

Earlier research experience involved developing techniques for mapping subsurface regional structures having interstate hydrologic significance, and defining ore bodies by geochemical prospecting.

Credentials

B.S., Biochemistry—Albright College (1966)

M.S., Hydrogeology—University of Delaware (1975)

Cooperative Program Environmental Engineering—University of Pennsylvania

Additional special course work in Geology and Hydrology, Franklin and Marshall College and Pennsylvania State University

Remote Sensing Data Processing Training, Goddard Space Center (1978)

OWRR Research Fellow, 1973

National Water Well Association, Technical Division.

Geological Society of America, Engineering Geological Division.

Society of Economic Paleontologists and Mineralogists

Employment History

1974-Present	WESTON
1973-1974	University of Delaware Water Resources Center
1971-1973	University of Delaware
1967-1971	Pennsylvania Department of Environmental Resources

Key Projects

Definition of groundwater contamination from sanitary landfill leachate and recovery of contaminants to protect heavily used aquifer in Delaware.

Field design studies for artificial recharge and waste disposal wells.

Design and construction of hydrologic isolation systems for various class hazardous wastes.

Design and supervision of chemical and physical rehabilitation of groundwater collection systems in fractured rock and coastal plain areas.

Principal investigator for six projects involving subsurface migration of PCB's in New York, New Jersey, Pennsylvania, and Oklahoma.

Design and construction supervision of hydrocarbon recovery wells in Pennsylvania.

Professional Profile

Geochemical evaluation of coal mine pools in West Virginia.

Geochemistry of subsurface migration of toxic substances.

Principal investigator for eight projects involving migration of volatile chlorinated hydrocarbons in groundwater.

Mineable reserve evaluations for coal, sand and gravel, limestone, clay deposits, mine reclamation, and monitoring.

Design geophysical and remote sensing assessments of hazardous waste disposal areas.

Publications

Leis, W., and R.R. Jordan, 1974, "Geologic Control of Groundwater Movement in a Portion of the Delaware Piedmont", OWRR—DEL 20.

Leis, W., 1976, "Artificial Recharge for Coastal Sussex County, Delaware", University of Delaware Press, Water Resources Center.

Leis, W., D.R. Clark, and A. Thomas, 1976, "Control Program for Leachate Affecting a Multiple Aquifer System, Army Creek Landfill, New Castle County, Delaware", National Conference on Management and Disposal of Residue on Land.

Leis, W., W.F. Beers, J.M. Davidson, and G.D. Knowles, 1978, "Migration of PCB's by Groundwater Transport—A Case Study of Twelve Landfills & Dredge Disposal Sites on the Upper Hudson Valley, New York", Proceedings of the 1st Annual Conference of Applied Research & Practice on Municipal and Industrial Waste.

Leis, W., R.D. Moose, and W.F. Beers, "Critical Area Maps, a Regional Assessment for Karst Topography", Association of Engineering Geologists 1978 Annual Meeting.

Leis, W., and W.F. Beers, "Soil Isotherm Studies to Predict PCB Migration Within Groundwater", (Abstract) ASTM 1979 Annual Meeting, Philadelphia, Pennsylvania.

Thomas, A., and W. Lein, "Physical & Chemical Rehabilitation of Contaminant Recovery Wells", Association of Engineering Geologists 1978 Annual Meeting.

Leis, W., W.F. Beers, and F. Benenati, "Migration of PCB's from Landfills and Dredge Disposal Sites in the Upper Hudson River Valley", New York Academy of Science Symposium on PCB's in the Hudson River.

Leis, W., "Subsurface Reclamation by Counter Pumping Systems: Geologic and Geotechnical Aspects of Land Reclamation", ASCE/AEG 1979 Symposium.

Leis, W., and A. Metry, "Field Characterization of Leachate Quality", Water Pollution Control Federation 1979 Annual Meeting.

Leis, W., and A. Metry, "Multimedia Pathways of Contaminant Migration", Water Pollution Control Federation 1980 Annual Meeting.

Leis, W., and K. Sheedy, "Geophysical Location of Abandoned Waste Disposal Sites", 1980 National Conference on Management of Uncontrolled Hazardous Waste Sites.

Sheedy, K., and W. Leis, 1982, "Hydrogeological Assessment in Karst Environments (chapter)."

Richard C. Balmer

Fields of Competence

Subsurface contamination investigations; well drilling, surveying and sampling; subsurface petroleum investigations; geologic and contour mapping; landfill investigations; gas chromatography and chemical testing, computer-generated contours and analysis; ground-penetrating radar (GPR) technician.

Experience Summary

Two years experience as an oilfield stratigraphic formation evaluation geologist; one year as a field geologist. Supervised drilling and installation of monitoring wells. Sampled and surveyed wells for detection of subsurface contamination. Conducted on-site evaluation of rock cuttings and subsurface investigations of presence of petroleum. Prepared computer-generated contour plots, isopath plots, and contamination plume contours.

Credentials

B.S., Geology—Dickinson College (1980)

Course work in oilfield practices and principles of subsurface investigation.

National Water Well Association

Employment History

1983-Present	WESTON
1981-1983	Exploration Logging, Inc.
1980	Ad + Soil Systems

Key Projects

Supervised drilling and installation procedures, and sampled and surveyed monitoring wells to detect presence of volatile organics and chromium contamination in groundwater.

Sampled monitoring wells for acid leachate.

Conducted subsurface investigations of facility effluent transport system using ground-penetrating radar.

Supervised drilling, decontamination and installation of monitoring wells at a major chemical plant; performed repeated sampling of wells.

Prepared computer-generated contaminant plume contours for use as evidence in a multimillion dollar lawsuit. Assisted in preparation of computer-generated contour plots of water table elevation and contaminant plumes for major projects.

Supervised drilling and sampling of test-borings in study of asbestiform-material landfills involving litigation. Calculated volume of material and generated isopath maps using the computer.

Monitored, interpreted and graphed hydrocarbon well data in an on-site logging unit. Prepared and described several thousand drilled-rock sedimentary rock samples. Conducted chemical analyses using gas chromatograph, dual micro-gas analyzers and various other pieces of equipment.

On-site Manager for a project involving application of organic by-products as fertilizer on farm fields in an environmentally-acceptable manner. Calculated application rates, reported on operations and served as contact person for farm personnel.

Professional Profile

Richard C. Balmer

Fields of Competence

Subsurface contamination investigations; well drilling, surveying and sampling; subsurface petroleum investigations; geologic and contour mapping; landfill investigations; gas chromatography and chemical testing, computer-generated contours and analysis; ground-penetrating radar (GPR) technician.

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Prepared computer-generated contaminant plume contours for use as evidence in a multimillion dollar lawsuit. Assisted in preparation of computer-generated contour plots of water table elevation and contaminant plumes for major projects.

Supervised drilling and sampling of test-borings in study of asbestiform-material landfills involving litigation. Calculated volume of material and generated isopath maps using the computer.

Monitored, interpreted and graphed hydrocarbon well data in an on-site logging unit. Prepared and described several thousand drilled-rock sedimentary rock samples. Conducted chemical analyses using gas chromatograph, dual micro-gas analyzers and various other pieces of equipment.

On-site Manager for a project involving application of organic by-products as fertilizer on farm fields in an environmentally-acceptable manner. Calculated application rates, reported on operations and served as contact person for farm personnel.

Professional Profile

Mark A. Hutson

Fields of Competence

Evaluation of geologic suitability and design of solid and hazardous waste disposal facilities; detection and abatement of organic and inorganic groundwater contamination; practical application of geophysical survey methods to hydrogeologic systems; evaluation of remedial actions for groundwater contamination control.

Experience Summary

Three years experience in hazardous waste disposal and associated groundwater contamination problems. Extent of contamination and remedial action assessments of waste disposal facilities. Hydrogeologic and soil contamination surveys of potential contaminant source areas. Site suitability studies for future waste disposal operations. Regulatory coordination between producers and disposers of waste materials to ensure proper disposal.

Credentials

B.S., Geology—Northern Illinois University (1978)

M.S., Geology—University of Illinois at Chicago (expected 1984)

Northern Illinois University—Part-time graduate studies in Business (1978-81)

National Water Well Association—Technical Division

American Water Resources Association

Employment History

1984-Present	WESTON
1982-1983	University of Illinois at Chicago Department of Geology
1980-1982	Ecology and Environment, Inc.
1978-1980	Illinois Environmental Protection Agency

Key Projects

Project manager and geologist on extent of contamination study of 3 disposal areas owned by a solvent recovery firm in northern Indiana.

Principal investigator and project manager of a hydrogeologic evaluation and remedial action plan preparation for a chemical waste disposal site in eastern Michigan.

Principal investigator on extent of contamination study involving a municipal waste disposal site in western Michigan.

Project manager of a team assigned to evaluate remedial action alternatives to a waste disposal facility in central Michigan.

Design of initial deep monitoring well system for use at an industrial facility in southeast Minnesota.

Field supervision of an investigation to determine groundwater quality and delineate extent of soil and groundwater contamination at an industrial facility in southern Ohio.

Conducted geologic reviews to determine site suitability for landfills, sewage sludge disposal, and industrial waste disposal.

Coordinator for generator and disposer guidance under RCRA and state waste disposal regulations.

Professional Profile

APPENDIX D

RELATIVE RESPONSE FACTORS FOR OVA

WESTON

CENTURY ORGANIC VAPOR ANALYZER

EXPLANATION OF TABLE:

A blank in the table indicates that no data is available for the analysis.

COMPOUND NAMES: Wherever possible compounds are listed under the chemical name used in the Merck Index.

EXPOSURE LIMITS: Exposure limits are those set by the Occupational Safety and Health Administration (OSHA) and were taken from the Federal Register 40, 23072 May 28, 1975. These limits were current at the time of printing the chart—August, 1981.

RELATIVE RESPONSE: CENTURY Organic Vapor Analyzers are factory calibrated to measure "total organic" vapors according to a standard (methane). Since different organic vapors interact with the flame ionization detector (FID) to varying extents, it is vital that the instrument user be aware of the magnitude of the variation in order to obtain the most accurate data. Each user must determine relative responses for his individual instrument.

CHROMATOGRAPHIC RETENTION TIME: For chromatographic work, the OVA can be used with a variety of column lengths and packing materials. For highest accuracy, temperature control for the column is mandatory. This is accomplished using the Portable Isothermal Pack (PIP) kit which is supplied with three 8 inch columns packed with B, G, and T materials respectively. (See following chart for packing material description.) Isothermal control is accomplished non-electrically using an ice/water mixture for 0°C and a seeded eutectic mixture for 40°C. The data listed are for comparison purposes only since retention time for a compound can vary due to the condition of the column packing material, packing procedure, and chemical interaction among the components of a vapor mixture.

COLUMN PACKING MATERIAL

B—3% Diisodecyl Phthalate on Anakrom A, AW, 60/80 mesh
E—20% Carbowax 400 on Anakrom C22A, AW, 60/80 mesh
G—10% OV-101 on Anakrom Q, 60/80 mesh
T—10% 1, 2, 3-Tris (2-cyanoethoxy) Propane on Anakrom C22A, AW, 60/80 mesh
PT—Porapak T, 60/80 mesh

AMBIENT AIR ANALYSIS:

Potentially toxic vapors and gases do not fill an area uniformly. Consequently, the measurement and control of these vapors can present a difficult problem for safeguarding the health of personnel. Foxboro manufactures a complete line of ambient air analyzers for on-the-spot testing as well as continuous area monitoring which have the sensitivity to detect and measure over 300 vapors and gases declared hazardous by OSHA. In addition, the analyzers are ideal for locating the source of the problems, such as a chemical leak or spill, and inadequate ventilation.

Foxboro Ambient Air Analyzers are currently being used for such applications as:

- Toxic gas and vapor analysis to comply with OSHA regulations
- Leak detection in chemical processes
- Analysis of anesthetic gases
- Measurement of vapor concentration in exposure chambers
- Analysis of vapor contaminants in "high purity" gases
- Analysis of industrial plant emissions
- Detecting breakthrough of vapors from respiratory cartridges or industrial adsorption systems
- Identify gases to aid in determining causes of fire
- Monitoring of hazardous waste and spill sites

WESTON

COMPOUND	Maximum Allowable Exposure (8 Hour Weighted Average) PPM	Relative Response (%)	Column Temperature (°C)	Column Packing (Retention Time in Minutes) [illegible]	[illegible]	[illegible]
Acetone	1000	60	0	0:37	0:27	1:50
			40	0:20	0:15	0:30
Acetonitrile	40	70	0	0:40	0:30	5:24
			40	0:20	0:18	1:15
Acrylonitrile	2	70	0	0:35	0:30	3:45
			40	0:19	0:17	0:51
Allyl Alcohol	2	30	0	1:15	0:44	11:45
			40	0:37	0:26	1:35
Allyl Chloride	1	50	0	0:16	0:28	0:31
			40	0:08	0:16	0:15
Benzene	10	150	0	0:50	1:19	1:43
			40	0:22	0:25	0:32
2-Bromo-2-chloro-1,1,1-trifluoroethane (Halothane)	–	45	0	0:37	0:35	0:58
			40	0:17	0:14	0:19
Bromoethane	200	75	0	0:15	0:26	0:23
			40	0:05	0:15	0:14
1-Bromopropane	–	75	0	0:21	0:58	0:40
			40	0:08	0:22	0:18
2-Butane	–	80	0	0:15	0:15	0:10
			40	–	–	–
n-Butanol	100	50	0	4:10	2:20	15:07
			40	0:24	0:53	1:44
2-Butanol	150	65	0	1:45	0:55	8:07
			40	0:24	0:24	0:53
n-Butyl Acetate	150	80	0	4:15	7:30	11:40
			40	0:50	1:14	1:31
n-Butyl Acrylate	–	60	0	–	–	–
			40	2:30	2:15	2:40
2-Butyl Acrylate	–	70	0	–	–	–
			40	1:22	1:45	1:46
n-Butyl Formate	–	50	0	2:15	2:57	4:40
			40	0:28	0:34	0:49
2-Butyl Formate	–	80	0	1:22	2:00	3:31
			40	0:20	0:26	0:37
n-Butyl Methacrylate	–	80	0	–	–	–
			40	4:03	5:46	5:10
2-Butyl Methacrylate	–	90	0	–	–	–
			40	2:46	3:40	3:34
Carbon Tetrachloride	10	10	0	0:20	1:24	0:37
			40	0:10	0:25	0:17
Chlorobenzene	75	200	0	5:45	8:00	11:20
			40	1:08	1:24	1:35
Chlorodifluoromethane (Freon 22)	1000	40	0	0:11	0:11	0:15
			40	–	–	–
Chloroform	50	65	0	0:55	0:57	2:00
			40	0:20	0:20	0:31
1-Chloropropane	–	75	0	0:16	0:31	0:23
			40	0:05	0:16	0:14
2-Chloropropane	–	90	0	0:15	0:23	0:18
			40	0:05	0:05	0:05
2-Chloro-1,1,2-trifluoroethyl difluoromethyl ether (Ethrane)	–	150	0	0:36	0:26	1:22
			40	0:13	0:12	0:19
Cumene	50	100	0	11:00	20:00	12:45
			40	2:20	3:03	2:19
Cyclohexane	300	85	0	0:36	1:25	0:19
			40	0:1[illegible]	0:26	0:14
Cyclohex[illegible]one	50	100	0	18:00	12:45	–
			40	3:00	2:00	–
n-Decan[illegible]	–	75	0	–	–	–
			40	2:5[illegible]	6:20	1:35
O-Dichlorobenzene	50	60	0	–	–	–
			40	8:06	10:00	11:20
Dichlorodifluoromethane (Freon 12)	1000	15	0	0:10	0:11	0:12
			40	–	–	–
1, 1 Dichloroethane	100	80	0	0:17	0:37	0:45
			40	0:08	0:17	0:18

WESTON

COMPOUND	Maximum Allowable Exposure (8 Hour Weighted Average) PPM	Relative Response (%)	Column Temperature (°C)	Column Packing (Retention Time in Minutes) [illegible]	[illegible]	[illegible]
1,2 Dichloroethane	50	80	0	1:14	1:08	3:50
			40	0:23	0:22	0:43
trans 1,2-Dichloroethylene	200	50	0	0:16	0:35	0:31
			40	0:05	0:18	0:16
Dichlorofluoromethane (Freon 21)	1000	70	0	0:16	0:15	0:23
			40	–	–	–
Dichloromethane	500	100	0	0:27	0:29	1:08
			40	0:10	0:10	0:22
1,2-Dichloropropane	75	90	0	0:41	1:49	2:56
			40	0:16	0:29	0:36
1,3-Dichloropropane	–	80	0	1:32	4:12	4:24
			40	0:26	0:47	1:20
1,2-Dichloro 1,1,2,2-tetrafluoroethane (Freon 114)	1000	110	0	0:12	0:12	0:14
			40	–	–	–
Diethyl Ether	400	50	0	0:20	0:26	0:19
			40	0:05	0:05	0:05
Diethyl Ketone	–	80	0	2:00	2:01	3:16
			40	0:29	0:30	0:49
p-Dioxane	100	30	0	3:15	2:09	6:40
			40	0:44	0:34	1:19
Ethane	–	80	0	0:15	0:15	0:15
			40	–	–	–
Ethanethiol	–	30	0	0:18	0:24	0:26
			40	0:13	0:12	0:14
Ethanol	1000	25	0	0:59	0:31	0:26
			40	0:26	0:22	0:43
Ethyl Acetate	400	65	0	0:48	1:00	2:20
			40	0:20	0:20	0:31
Ethyl Acrylate	25	40	0	1:40	2:10	4:08
			40	0:30	0:30	0:50
Ethyl Benzene	100	100	0	6:10	9:31	7:44
			40	1:15	1:35	1:35
Ethyl Butyrate	–	70	0	4:34	6:22	8:00
			40	0:48	1:07	1:24
Ethyl Formate	100	40	0	0:25	0:29	1:05
			40	0:16	0:17	0:20
Ethyl Methacrylate	–	70	0	4:13	6:13	6:20
			40	0:47	1:01	1:01
Ethyl Propionate	–	65	0	1:40	2:48	4:10
			40	0:25	0:35	0:50
Ethylene Dibromide	20	50	0	5:20	4:51	15:00
			40	1:00	0:55	2:43
Ethylene Dichloride	50	60	0	1:07	1:08	3:45
			40	0:20	0:21	0:50
Ethylene Oxide	50	70	0	0:10	0:13	0:20
			40	–	–	–
Fluorotrichloromethane (Freon 11)	1000	10	0	0:15	0:18	0:17
			40	–	–	–
Heptane	500	75	0	0:50	2:20	0:27
			40	0:20	0:30	0:16
Hexane	500	70	0	0:23	0:50	0:20
			40	0:13	0:20	0:13
Isoprene	–	50	0	0:10	0:23	0:20
			40	0:05	0:05	0:05
Methane	–	100	0	0:05	0:05	0:05
			40	–	–	–
Methyl Alcohol	200	12	0	0:37	0:21	2:23
			40	0:22	0:14	0:45
Methyl Acetate	200	41	0	0:30	0:30	1:30
			40	0:17	0:15	0:24
Methyl Acrylate	10	40	0	0:50	0:58	2:30
			40	0:20	0:21	0:37
Methyl Cyclohexane	500	100	0	0:54	2:37	0:26
			40	0:18	0:33	0:17
Methyl Cyclopentane	–	80	0	0:22	1:02	0:17
			40	0:05	0:19	0:05

WESTON

COMPOUND	Maximum Allowable Exposure (8 Hour Weighted Average) PPM	Relative Response (%)	Column Temperature (°C)	Column Packing (Retention Time in Minutes) B	O	T
Methyl Ethyl Ketone	200	80	0	1:00	0:50	3:30
			40	0:22	0:20	0:43
Methyl Isobutyl Ketone	100	80	0	4:20	3:15	7:30
			40	0:42	0:40	1:25
Methyl Methacrylate	100	50	0	1:41	2:22	4:08
			40	0:27	0:31	0:55
Methyl Propyl Ketone	200	70	0	2:20	2:05	8:14
			40	0:33	0:32	0:52
Nitromethane	100	35	0	0:51	0:40	3:00
			40	0:25	0:19	1:31
1-Nitropropane	25	60	0	4:50	2:50	25:00
			40	0:46	0:41	4:05
2-Nitropropane	25	70	0	2:53	1:51	10:00
			40	0:35	0:31	1:52
Nonane	–	90	0	7:26	8:00	2:32
			40	1:08	2:40	0:42
Octane	500	80	0	2:47	7:39	1:07
			40	0:39	1:09	0:27
Pentane	1000	65	0	0:18	0:25	0:14
			40	0:12	0:12	0:12
Pentanol	–	40	0	12:00	6:00	20:00
			40	2:44	1:17	3:36
Propane	1000	80	0	0:05	0:11	0:05
			40	–	–	–
n-Propanol	200	40	0	2:50	1:00	6:30
			40	0:35	0:30	1:05
2-Propanol	400	65	0	1:13	0:30	3:43
			40	0:25	0:20	0:38
n-Propyl Acetate	200	75	0	2:04	2:52	5:52
			40	0:30	0:38	0:51
n-Propyl Ether	–	65	0	1:37	2:06	1:15
			40	0:43	0:29	0:18
n-Propyl Formate	–	50	0	0:46	1:07	2:10
			40	0:17	0:18	0:27
Pyridine	5	128	0	8:00	4:15	–
			40	–	1:26	–
Styrene	100	85	0	20:00	25:00	28:00
			40	2:06	2:26	2:39
1,1,1,2-Tetrachloroethane	–	100	0	8:25	7:48	10:00
			40	1:16	1:27	1:37
1,1,2,2-Tetrachloroethane	5	100	0	32:00	14:00	50:00
			40	4:09	2:37	7:51
Tetrachloroethylene	100	70	0	3:00	5:45	2:10
			40	0:41	1:06	0:33
Tetrahydrofuran	200	40	0	1:05	1:05	1:45
			40	0:23	0:23	0:30
Toluene	200	110	0	2:30	4:05	4:30
			40	0:38	0:47	0:53
1,1,1 Trichloroethane	350	105	0	0:31	1:10	0:47
			40	0:15	0:23	0:20
1,1,2 Trichloroethane	10	85	0	5:13	3:43	16:00
			40	0:40	0:45	2:30
Trichloroethylene	100	70	0	1:17	2:02	1:25
			40	0:23	0:28	0:28
Trichlorotrifluoroethane (Freon 113)	1000	80	0	0:15	0:30	0:16
			40	0:13	0:14	0:13
Triethylamine	25	70	0	–	2:49	–
			40	–	–	–
Vinyl Acetate	–	50	0	0:34	0:43	1:55
			40	0:15	0:17	0:30
Vinylidene Chloride	–	40	0	0:20	0:25	0:22
			40	0:13	0:14	0:14
m-Xylene	100	111	0	2:38	12:03	8:31
			40	0:39	1:43	1:17
o-Xylene	100	118	0	3:29	15:07	8:40
			40	0:48	1:58	1:46
p-Xylene	100	118	0	2:46	12:25	8:23
			40	0:39	1:42	1:18

APPENDIX E

Relative Response Factors for HNu

H-Nu PHOTOIONIZATION DETECTOR
RELATIVE SENSITIVITIES FOR VARIOUS GASES

(10.2 eV Lamp)

Species	Photoionization Sensitivity*
p-xylene	11.4
m-xylene	11.2
benzene	10.0 (reference standard)
toluene	10.0
diethyl sulfide	10.0
diethyl amine	9.9
styrene	9.7
trichloroethylene	8.9
carbon disulfide	7.1
isobutylene	7.0
acetone	6.3
tetrahydrofuran	6.0
methyl ethyl ketone	5.7
methyl isobutyl ketone	5.7
cyclohexanone	5.1
naptha (86% aromatics)	5.0
vinyl chloride	5.0
methyl isocyanate	4.5
iodine	4.5
methyl mercaptan	4.3
dimethyl sulfide	4.3
allyl alcohol	4.2

*Expressed in ppm (V/V)

H-Nu PHOTOIONIZATION DETECTOR
RELATIVE SENSITIVITIES FOR VARIOUS GASES

(10.2 eV Lamp)

Species	Photoionization Sensitivity*
propylene	4.0
mineral spirits	4.0
2,3-dichloropropene	4.0
cyclohexene	3.4
crotonaldehyde	3.1
acrolein	3.1
pyridine	3.0
hydrogen sulfide	2.8
ethylene dibromide	2.7
n-octane	2.5
acetaldehyde oxime	2.3
hexane	2.2
phosphine	2.0
heptane	1.7
allyl chloride (3-chloropropene)	1.5
ethylene oxide	1.0
acetic anhydride	1.0
α-pinene	0.7
dibromochloropropane	0.7
epichlorohydrin	0.7
nitric oxide	0.6
β-pinene	0.5

*Expressed in ppm (V/V)

H-Nu PHOTOIONIZATION DETECTOR
RELATIVE SENSITIVITIES FOR VARIOUS GASES

(10.2 eV Lamp)

Species	Photoionization Sensitivity*
citral	0.5
acetic acid	0.1
nitrogen dioxide	0.02
methane	0.0
acetylene	0.0
ethylene	0.0

*Expressed in ppm (V/V)

APPENDIX F

Boring Logs and Well Completion Summaries

DRILLING LOG

WELL NUMBER: B-1
OWNER: U.S.A.F.
LOCATION: east of Pump House H (Bldg. 678)
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH: 20.2'
SURFACE ELEVATION: -
WATER LEVEL: 15'
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Auger
DATE DRILLED: 12/28/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson /RCB

SKETCH MAP

NOTES: * Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE Interval	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*	0-3	0-2': Black to reddish brown mottled CLAY with some silt and trace pebbles; organic rich, firm, medium plasticity, dry to moist. (CL)
		2	CC	3-9	
					2 - 9': Grayish brown fine SAND with trace silt, dry; OVA - Oppm. (SM)
		3	CC	9-13	9-10.5': Reddish brown to black mottled CLAY with some sand and silt; firm to hard; OVA=Oppm. (CL)
)					10.5-13.5:' Black to dark gray to greenish gray CLAY with trace silt; hard trace orange mottling, moist; OVA= 0 ppm. (CL)
		4	CC	13-18	13.5-16:' Reddish brown to dark brown CLAY with some silt; stiff, plastic, moist. (CL)
5					16-20.2': Gray to Reddish brown mottled CLAY with some silt;
		5	CC	18-20.2	stiff, plastic, wet. OVA=3 ppm; HNu= Oppn. (CL)
					Refusal at 20.2 Water at 15' in open hole.
)/20.2					Hole was backfiled at completion of logging.

* A.S.T.M D1586

WOODWARD-CLYDE CONSULTANTS

DRILLING LOG

WELL NUMBER: B-2
OWNER: U.S.A.F.
LOCATION: NE corner of pump house G (Bldg 674)
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH: 16.4'
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Auger
DATE DRILLED: 12/13/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson/ RCB

SKETCH MAP

NOTES: * Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE Interval	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*	0-3'	0-11': Dark brown to reddish brown CLAY with some silt and sand, and trace pebbles; some layers more sandy and reddish colored; hard, plastic, moist; OVA 0 ppm (CL)
		2	CC	3-8'	
		3	CC	8-13'	
					11-15':Dark gray CLAY, organic-rich, stiff, plantic, moist. OVA= 55 ppm, HNu= 0 sampled. (CL)
		4	CC	13-16.4'	
					15-16.4':Reddish brown to gray mottled CLAY with some silt and sand, and trace gravel; firm, plastic. OVA= Oppm. (CL)
					Refusal at 16.4'
					Hole was backfilled at completion of logging.

* ASTM D1586

SHEET 1 OF 1

WOODWARD-CLYDE

DRILLING LOG

WELL NUMBER B-3

OWNER U.S.A.F.

LOCATION West of pump house F. (BLdg 671)

ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 8'

SURFACE ELEVATION

WATER LEVEL: 3'

DRILLING COMPANY Terracon

DRILLING METHOD Hollow Auger

DATE DRILLED 12/13/84

DRILLER R. Kelly

HELPER D. Ritter

LOG BY M. Hutson /RCB

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE interval	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*	0-3	0-2' Reddish brown and dark brown mottled CLAY with some silt and sand; firm, moist. (CL)
		2	CC	3-8	2-5' Light brown SAND with little silt, wet at 3' (SM)
					5-8' Light gray SAND with little silt, wet (SM)
8					
					Hole was backfilled at completion of logging.

* ASTM D1586

WOODWARD-CLYDE

DRILLING LOG

WELL NUMBER: B-4
OWNER: U.S.A.F.
LOCATION: Hydrant C and storm sewer on row 8
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH:
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Auger
DATE DRILLED: 12/14/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson /RCB

SKETCH MAP

NOTES: * Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE INTERVAL	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0		1	CC*	0-3	0-1.7':Concrete - water running into hole at base of concrete
		2	CC	3-6.7	1.7'-2.7': Gray silty sand, slightly cohesive, wet; OVA= 50 ppm; HNu=0. (SM)
5					2.7-6.7:' Dark gray, organic rich silt and sand; cohesive, firm, wet: OVA=55 ppm; HNu= 0 ppm (SM-ML)
					Boring terminated 6.7' below the surface Hole was backfilled at completion of logging.
10					

* A.S.T.M D1586

DRILLING LOG

WELL NUMBER: B-5
OWNER: U.S.A.F.
LOCATION: Northwest of hydrent B on line 7
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH: 18.8'
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Auger
DATE DRILLED: 12/14/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson

SKETCH MAP

NOTES
* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE Interval	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					0-1.7' .3' Asphalt, then concrete
		1	CC*	1.7 - 6.7	
					1.7-13' Dark gray to greenish gray CLAY with silt and abundant organic material; hard, very plastic, dry. OVA=55ppm. HNu=0. (CL)
		2	CC	6.7 - 11.7	
0					
					13-16' Reddish brown to dark gray mottled CLAY with some silt, little organic matter; firm, medium, plasticity, moist. OVA=1.5 ppm. HNu=0 (CL)
		3	CC	11.7 - 16.7	
5					
					16-18.8' Reddish brown mottled weathered LIMESTONE
		4	CC	16.7 - 18.8	
3.8					
					Refusal at 18.8. Hole was backfilled at completion of logging.

* ASTM D1586

WOODWARD-CLYDE CONSULTANTS

DRILLING LOG

WELL NUMBER: B-6
OWNER: U.S.A.F.
LOCATION: between rows 4 and 5
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH: 13.1'
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Auger
DATE DRILLED: 12/14/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson

SKETCH MAP

NOTES
* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE Interval	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					0-1.7' .2' Asphalt, then concrete
		1	CC*	1.7-6.7	
					1.7-6.7:' Dark gray to black organic CLAY, firm to hard, plastic
					dry. (CL)
					6.7-11.7:' Light gray to reddish brown mottled CLAY with some
					silt and abundant organic matter, firm, medium plastic, dry:
					OVA=100 ppm. HNu= 0 ppm. (CL)
		2	CC	6.7-11.7	
					11.7-13.1': Reddish brown mottled CLAY with silt and abundant
					organic matter; OVA= 50 ppm. HNu=Oppm. (CL)
		3	CC	11.7-13.1	
					Refusal at 13.1' - fossiliferous limestone.
					Hole was backfilled at completion of logging.

* ASTM D1586

DRILLING LOG

WELL NUMBER B-7

LOCATION Between rows 2 and 3 at Baker spot

SURFACE ELEVATION

DRILLING COMPANY Terracon

DRILLER R. Kelly

LOG BY M. Hutson

OWNER U.S.A.F.

ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 13.2'

WATER LEVEL

DRILLING METHOD Hollow Auger

DATE DRILLED 12/29/84

HELPER D. Ritter

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE Interval	DESCRIPTION/SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					0 - .4' Asphalt
					.4 - 1.7' Concrete
		S-1	CC*	1.7-3.2	1.7 - 3.2' No Recovery
		s 2	CC	3.2-8.2	3.2 - 8.2'
					3.2 - 5.5 Bluish gray, mottled, silty Clay;
					hard, low plasticity, dry, organic rich: (CL)
					5.5 - 8.2 Light brown to blue gray, mottled, silty
					clay; hard, low plasticity, dry, organic rich:(CL)
					OVA=20ppm HNu=0ppm
		S-3	CC	8.2-13.2	8.2 - 13.2 Light brown to blue gray, m ttled, silty clay;
					ha d, low plasticity; dry, organic rich:(CL)
					OVA=20ppm HNu=13 ppm
					Boring terminated at 13.2'
					Hole was backfilled at completion of logging.

1 1

* ASTM D1586

DRILLING LOG

WELL NUMBER B-8
LOCATION Northeast corner of tank farm next to drainage ditch
SURFACE ELEVATION
DRILLING COMPANY Terracon
DRILLER R. Kelly
LOG BY M. Hutson

OWNER U.S.A.F.
ADDRESS Forbes Field Topeka, KS
TOTAL DEPTH 11'
WATER LEVEL:
DRILLING METHOD Hollow Auger
DATE DRILLED 12/27/84
HELPER D. Ritter

SKETCH MAP

NOTES
* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*		0-3' Topsoil, (12" recovery)
		2	CC		3-8'
					3-5' Light gray to orangish brown, mottled, silty clay; firm, moist, medium plasticity (CL)
					5-8' dark brown to orangish brown, very silty clay w/some sand, firm, moist, low plasticity. (CL). HNu= 0 ppm OVA=0 ppm
		3	CC		8-11' Light brown to gray, mottled, silty clay with some weathered shale fragments; firm, moist, cohesive, (CL) OVA= 0ppm HNu=0ppm
					Boring terminated at 11' below surface
					Hole was backfilled at the completion of logging.

* ASTM D1586

SHEET 1 OF 1

DRILLING LOG

WELL NUMBER B-9
LOCATION Along storm drain at the west end of Row 3
SURFACE ELEVATION
DRILLING COMPANY Terracon
DRILLER R. Kelly
LOG BY M. Hutson

OWNER U.S.A.F.
ADDRESS Forbes Field Topeka, KS
TOTAL DEPTH 12.7
WATER LEVEL
DRILLING METHOD Hollow Auger
DATE DRILLED 12/29/84
HELPER D. Ritter

SKETCH MAP

NOTES
* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*		0-3'
					0-1.4' Topsoil
					1.4-3' Light Brown, mottled silty Clay; firm, moist, low plasticity (CL)
		2	CC		3-8'
					3-12.7' Brown, mottled clay w/ abundant organic matter; hard, moist, plastic wet below 10', (CL)
		3	CC		8-12.7'
					Auger refusal at 12.7'
					Boring was backfilled at completion of logging.

* ASTM D1586

SHEET 1 OF 1

DRILLING LOG

WELL NUMBER B-10 OWNER U.S.A.F.

LOCATION along Row 8 15 feet west of Able spot ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 4

SURFACE ELEVATION WATER LEVEL

DRILLING COMPANY Terracon DRILLING METHOD Hollow Auger DATE DRILLED 12/29/84

DRILLER R. Kelly HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					0-1' Concrete - water at base of concrete
		1	CC*		1-4'
					1- 3.6' Gray silty Sand and Gravel
					soft, wet. (SM-GP) OVA=10 ppm, HNu=4ppm
					3.6-4' Blue gray silty Clay; soft, moist, plastic (CL)
4					
					Boring terminated 4' below the surface.
					Hole was backfilled at completion of logging.

* ASTM D1586

SHEET _ OF _

WESTON

DRILLING LOG

WELL NUMBER: SW-1
OWNER: U.S. A. F.
LOCATION: Adjacent to DW-5
ADDRESS: Topeka, KS
TOTAL DEPTH: 10'
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Hollow Stem Auger
DATE DRILLED: 12/28/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0		1	CC*		0-3'
					0-2' Dark gray, organic rich, topsoil
					2-3.5' Brown silty sand, medium grained, dry (SM)
		2	CC		3-8'
					3.5-7' Dark gray, silty clay; hard, moist, organic rich
5					7-8' Dark gray to brown, mottled, silty clay w/abundant sand; firm, wet, low plasticity, (CL-SC), OVA=3 ppm HNu=0 ppm
		3	CC		8-10' Dark gray to brown, silty clay; hard, moist, medium plasticity, (CL) OVA=0 ppm, HNu=0 ppm
10					
					Boring terminated 10' below the surface

* A.S.T.M. D1586

SHEET 1 OF 1

Well SW-1

Well Construction Summary

Location or Coords: Adjacent to DW-5

Elevation: Ground Level

Top of Casing

Project Forbes Field

Location Topeka, KS

Personnel M. Hutson

Drilling Summary:

Total Depth 10'

Borehole Diameter 6"

Driller Terracon Consultants

Rig CME 55

Bit(s) 6" dia. auger

Drilling Fluid

Surface Casing

Well Design:

Basis: Geologic Log ____ Geophysical Log ____

Casing String(s): C = Casing S = Screen

0 - 5	C	
5 - 10	S	

Casing: C1 2" dia. sch. 40 PVC

C2

Screen: S1

S2

Centralizers Bentonite pellets

Filter Material Graded sand

Cement

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling: 6" hole	12/28	0740	12/28	0805
Geophys. Logging:				
Casing: 2" PVC	12/28	0805	12/28	0815
Filter Placement:	12/28	0815	12/28	0820
Cementing:				
Development:				
Other:				

Well Development:

Well developed by bailing

Comments:

WESTON

DRILLING LOG

WELL NUMBER SW-2
OWNER U.S.A.F.
LOCATION Along fuel line at end of Row 8
ADDRESS Forbes Field, Topeka, KS
TOTAL DEPTH 8.5'
SURFACE ELEVATION
WATER LEVEL
DRILLING COMPANY Terracon
DRILLING METHOD Hollow Auger
DATE DRILLED 12/28/84
DRILLER R. Kelly
HELPER D. Ritter
LOG BY M. Hutson

SKETCH MAP

NOTES
* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*		DESCRIPTION/SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*		0-3.5'	0-1' Black to dark gray Topsoil
						1-7' Orangish brown to light gray mottled clay fill w/ some sand, gravel, and organic materials firm moist, medium plasticity wet at 5; OVA= 0 ppm, HNu= 0 ppm
		2	CC		3.5-6	
		3	CC		6-8.5'	7-8.5' Dark gray, silty clay; hard, wet, plastic (CL), OVA= 0 ppm, HNu= 0 ppm.
						Boring terminated 8.5' below surface

* ASTM D1586

SHEET 1 OF 1

Topeka, KS

Location

M. Hutson

Personnel

Forbes Field

Project

Well SW-2

Well Construction Summary

Location or Coords: Along fuel line at end of Row 8

Elevation: Ground Level

Top of Casing

Drilling Summary:

Total Depth 8'

Borehole Diameter 6" diameter

Driller Terracon Consultants

Rig CME 55

Bit(s) 6" dia.

Drilling Fluid

Surface Casing

Well Design:

Basis: Geologic Log ____ Geophysical Log ____

Casing String(s): C = Casing S = Screen

0 - 3	C	
3 - 8	S	

Casing: C1 2' dia. , sch. 40, PVC

C2

Screen: S1

S2

Centralizers Bentonite Pellets

Filter Material Graded Sand

Cement

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling 6" hole	12/28	0850	12/28	0930
Geophys. Logging:				
Casing 2" PVC	12/28	0930	12/28	0940
Filter Placement	12/28	0940	12/28	0950
Cementing				
Development:				
Other				

Well Development:

Well developed by bailing

Comments:

WESTON

DRILLING LOG

WELL NUMBER SW-3 OWNER U.S.A.F.

LOCATION west end of lateral 7 ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 16.5'

SURFACE ELEVATION WATER LEVEL

DRILLING COMPANY Terracon DRILLING METHOD Hollow Auger DATE DRILLED 12/28/84

DRILLER R. Kelly HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

* Continuous Core

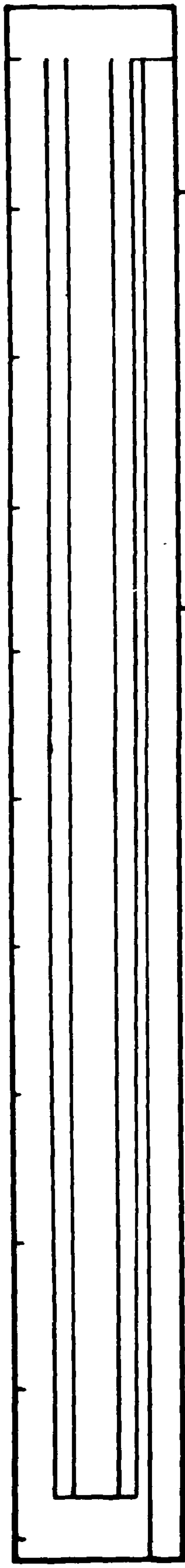
DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*		DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
		1	CC*		0-3'	0-1' Topsoil
						1-2' Brown to light gray, mottled sandy Clay fill; firm, moist, plastic, organic rich (CL)
		2	CC		3-8'	2-3' Black sandy Clay ; hard, moist, plastic organic rich, OVA=10 ppm, HNu= 0 ppm.
						3-5' Light gray to brown, mottled, sandy Clay fill; firm, moist medium plasticity (CL) OVA= 0 ppm HNu= 0 ppm
						5-6.5' Dark gray to brown, mottled, silty Clay ; soft, moist, low plasticity (CL) OVA= 0 ppm HNu= 0 ppm.
		3	CC		8-13'	6.5-13' Black, silty Clay , hard. dry, low plasticity, organic rich (OL) OVA= 0 ppm, HNu = 0 ppm
		4	CC		13-16.5'	13-16.5' Blue gray to light brown, mottled silty Clay, hard, wet, low plasticity; (CL) OVA= 0 ppm, HNu= 0 ppm, Boring terminated at 16.5'

* ASTM D1586

Project: Forbes Field

Location: Topeka, KS

Personnel: M. Hutson



Well: SW-3

Well Construction Summary

Location or Coords: ______

Elevation: Ground Level ______

Top of Casing ______

Drilling Summary:

Total Depth: 16.0'

Borehole Diameter: 6"

Driller: Terracon Consultants

Rig: CME-55

Bit(s): 6" flight auger

Drilling Fluid: ______

Surface Casing: ______

Well Design:

Basis: Geologic Log x Geophysical Log ______

Casing String(s): C = Casing S = Screen

0 - 11	C	
11 - 16	S	

Casing: C1 2" dia. sch 40, PVC

C2 ______

Screen: S1 5' sch 40, PVC

S2 ______

Centralizers ______

Filter Material graded sand

Cement ______

Other ______

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling: 6" hole	12/28	10 45	12/28	11:15
Geophys. Logging:				
Casing: 2" dia.	12/28	11 15	12/28	11 25
Filter Placement.	12/28	11 25	12/28	11 35
Cementing				
Development:	1/2		1/2	
Other				

Well Development:

well developed by bailing

Comments:

WESTON

WESTON

DRILLING LOG

WELL NUMBER	SW-4	OWNER	U.S.A.F.
LOCATION	between laterals 7 and 8, 15' west of Able row	ADDRESS	Forbes Field Tyreka, KS
		TOTAL DEPTH	11'
SURFACE ELEVATION		WATER LEVEL	
DRILLING COMPANY	Terracon	DRILLING METHOD	Hollow stem/Angers
DATE DRILLED	12/28/84		
DRILLER	R. Kelly	HELPER	D. Ritter
LOG BY	MAH		

SKETCH MAP

NOTES

*continuous core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					0 - .3' Asphalt
					.3 - 1.7' Concrete
		1	CC*		1.7 - 3.2' 1.7 - 4' Blue-gray, Clay; soft, moist, plastic: (CL) OVA=30ppm, HNu=0ppm.
5		2	cc		3.2 - 8.2 4-6' Gray to orangish brown mottled, sandy Clay; firm, moist, plastic, (CL) OVA = 0ppm, HNu= 0 ppm
					6 - 9' Dark gray, clay; hard,
		3	cc		8.2 - 11' moist, low plasticity, (CL) OVA=100ppm, HNu, =0ppm
					9 - 11' Blue Gray, organic rich Clay ; firm, moist, medium plastic (CL) OVA=0ppm, HNu = 0ppm.
10					
					Boring terminated 11 feet below the surface

*ASTM D1586

SHEET 1 OF 1

Well SW-4

Well Construction Summary

Location or Coords: ______

Elevation: Ground Level ______

Top of Casing ______

Location Topeka, KS

Personnel M. Hutson

Project Forbes Field

Drilling Summary:

Total Depth 11'

Borehole Diameter 6"

Driller Terracon Consultants

Rig CME-55

Bit(s) 6" ager

Drilling Fluid ______

Surface Casing ______

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling 6"hole	12/28	13[20]	12/28	13[50]
Geophys. Logging				
Casing 2"pvc	12/28	13[50]	12/28	14[00]
Filter Placement	12/28	14:00	12/28	14:15
Cementing				
Development				
Other				

Well Design:

Basis: Geologic Log x Geophysical Log ______

Casing String(s): C = Casing S = Screen

0 - 6	C	
6 - 11	S	

Casing C1 2" dia, sch, 40 PVC

C2 ______

Screen S1 ______

S2 ______

Centralizers Bentonite Pellets

Filter Material graded sand

Cement ______

Other ______

Well Development:

well developed by bailing

Comments:

WESTON

WOODWARD-CLYDE

DRILLING LOG

WELL NUMBER SW-5 OWNER U.S.A.F.

LOCATION at intersection of storm sewer and fuel lines east of pump house ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 7.7'

SURFACE ELEVATION WATER LEVEL:

DRILLING COMPANY Terracon DRILLING METHOD Hollow Auger DATE DRILLED 12/28/84

DRILLER R. Kelly HELPER: D. Ritter

LOG BY: M. Hutson

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION/SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0		1	CC*		0-3' 0-2' Black to orangish brown mottled silty clay, fill & dry, soft, fill. (CL)
					2-2.5' Brown, Sand & dry, non-cohesive, medium grained, fill; (SP) OVA=0ppm HNu=0ppm.
5		2	cc		3-7.5' 2.5 - 7.5' Blue gray to black, mottled, sandy clay, fill, soft, moist, plastics OVA=500ppm, HNu=400ppm.
					Boring terminated 7.5 feet below the surface
10					

* A.S.T.M D1586

SHEET 1 OF 1

Well SW-5

Well Construction Summary

Location or Coords: ____________ Elevation Ground Level ____________

Top of Casing ____________

Location ____________

Personnel ____________

Project ____________

Drilling Summary:

Total Depth 7.7'

Borehole Diameter 6"

Driller Terracon Consultants

Rig CME 55

Bit(s) 6" Auger

Drilling Fluid ____________

Surface Casing ____________

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling 6" hole	12/28	15 20	12/28	15 30
Geophys Logging				
Casing 2"PVC	12/28	15 30	12/28	15 40
Filter Placement	12/28	15 40	12/28	15 50
Cementing				
Development				
Other				

Well Design:

Basis: Geologic Log x Geophysical Log ____

Casing String(s): C = Casing S = Screen

0	- 2.7	C
2.7	- 7.7	S

Casing C1 2", Sch. 40, PVC.

C2 ____________

Screen: S1 2", Sch. 40, PVC.

S2 ____________

Centralizers Bentonite pellets

Filter Material Graded sand

Cement ____________

Other ____________

Well Development:

well developed by bailing

Comments:

WESTON DESIGNERS CONSULTANTS

DRILLING LOG

WELL NUMBER SW-6 OWNER U.S.A.F.

LOCATION Along storm drain, east of building G77 ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 11.9'

SURFACE ELEVATION WATER LEVEL

DRILLING COMPANY Terracon DRILLING METHOD Hollow Auger DATE DRILLED 12/28/84

DRILLER R. Kelly HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

* Continuous Core

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0		1	CC		0-3' 0-2 Black, organic rich topsoil
					2-4.5' Dark brown, organic rich, silty clay; mottled, soft, moist, plastic, (CL) OVA=Oppm,
		2	CC		3-8'
					4.5-10.3' Blue gray to black, sandy clay w/trace gravel and abundent organics moist, soft to firm, low to medium plasticity, (CL); wet at 9'; OVA-Oppm, HNu=Oppm
		3	CC		8-11.5'
0					
					10.3-11.9' Brown mottled silty clay; moist, firm low plasticity, (CL) OVA=Oppm, HNu=Oppm
					Boring terminated 11.9' below the surface

*ASTM D1586

Well SW-6

Well Construction Summary

Location or Coords. ______ Elevation Ground Level ______

Top of Casing ______

Project: Forbes Field

Location: Topeka, KS

Personnel: M. Hutson

Drilling Summary:

Total Depth: 11.9

Borehole Diameter: 6"

Driller: Terracon Consultants

Rig: CME-55

Bit(s): 6"Ager

Drilling Fluid: ______

Surface Casing: ______

Well Design:

Basis: Geologic Log x Geophysical Log ______

Casing String(s): C = Casing S = Screen

0	7.9	C
7.9	11.9	S

Casing C1: 2"dia, sch.40, PVC

C2: ______

Screen: S1: 2"dia, sch. 40 PVC

S2: ______

Centralizers: bentonite pellets

Filter Material: graded sand

Cement: ______

Other: ______

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling: 6"hole	12/28	16⁰⁰	12/28	16¹⁵
Geophys. Logging:				
Casing: 2" PVC	12/28	16¹⁵	12/28	16²⁰
Filter Placement	12/24	16²⁰	12/28	16
Cementing				
Development				
Other				

Well Development:

well developed by bailing

Comments:

WESTON

DRILLING LOG

WELL NUMBER	DW-1	OWNER	U.S.A.F.
LOCATION	North of Civil Engineering Building on grass	ADDRESS	Forbes Field Topeka, KS
		TOTAL DEPTH	55'
SURFACE ELEVATION		WATER LEVEL	
DRILLING COMPANY	Terracon	DRILLING METHOD	Rotary
DATE DRILLED	12/17/84		
DRILLER	R. Kelly	HELPER	D. Ritter
LOG BY	M. Hutson / RCB		

SKETCH MAP

NOTES

Logged by drilling rate and cuttings

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					Topsoil 1.0'
					Dark brown, silty clay, stiff moist 16.1'
					Limestone 18.0'
					Shale 24.5'
					Limestone 28.4'
30					Shale

* ASTM D1586

SHEET 1 OF 2

DRILLING LOG

WELL NUMBER	DW-1 (cont.)	OWNER	U.S.A.F.
LOCATION		ADDRESS	Forbes Field Topeka, KS
		TOTAL DEPTH	
SURFACE ELEVATION		WATER LEVEL	
DRILLING COMPANY	Terracon	DRILLING METHOD	Rotary
DATE DRILLED	12/17/84		
DRILLER	R. Kelly	HELPER	D. Ritter
LOG BY	M. Hutson		

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					
					Shale
0					
					55'
					Boring terminated 55' below the surface.
0					
70					
0					

* ASTM D1586

SHEET 2 OF 2

Project Forbes Field
Location Topeka, KS
Personnel M. Hutson

Well DW-1

Well Construction Summary

Location or Coords: North of Civil Engineering Building on grass

Elevation: Ground Level

Top of Casing

Drilling Summary:

Total Depth 55'

Borehole Diameter 8" to 21.1'
3.5" to 55'

Driller Terracon

Rig CME - 55

Bit(s) 8" roller bit
3.5" roller bit

Drilling Fluid clean water

Surface Casing

Well Design:

Basis: Geologic Log ____ Geophysical Log ____

Casing String(s): C = Casing S = Screen

0 - 21.1	C	
21.1 - 55	Open	

Casing: C1 4"diameter, sch, 80 PVC

C2

Screen: S1

S2

Centralizers

Filter Material

Cement

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling				
8"hole	12/14	15^{15}	12/14	17^{30}
3.5"hole	12/27	11:15	12/27	12:23
Geophys. Logging:				
Casing				
4" PVC	12/15	9:45	12/15	10:00
Filter Placement:				
Cementing:	12/15	11:00	12/15	11:15
Development:				
Other:				

Well Development:

Developed by blowing with compressed air

Comments:

WESTON

DRILLING LOG

WELL NUMBER: DW-2
OWNER: U.S.A.F.
LOCATION: On ramp East of Row 3
ADDRESS: Forbes Field, Topeka, KS
TOTAL DEPTH: 52.7'
SURFACE ELEVATION:
WATER LEVEL:
DRILLING COMPANY: Terracon
DRILLING METHOD: Rotary
DATE DRILLED: 12/17-26/84
DRILLER: R. Kelly
HELPER: D. Ritter
LOG BY: M. Hutson/RCB

SKETCH MAP

NOTES

~~Logged by drilling rate and~~ cuttings

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)	
0					Asphalt and Concrete	2.2'
					Dark brown, silty clay	
10						16.3'
					Weathered Shale	18.1'
					Limestone	19.4'
20					Limestone w/ shale seams	24.2'
					Shale	25.0'
					Limestone	27.4'
30					Shale	40'
40						

* ASTM D1586

SHEET 1 OF 2

DRILLING LOG

WELL NUMBER DW-2 (Cont)

OWNER U.S.A.F.

LOCATION

ADDRESS Forbes Field
Topeka, KS

TOTAL DEPTH

SURFACE ELEVATION

WATER LEVEL

DRILLING COMPANY Terracon

DRILLING METHOD Rotary

DATE DRILLED 12/17-26/8[illegible]

DRILLER R. Kelly

HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS *	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					
					Shale w/some sand stringers
					48.5'
					Shale w/some limestone stringers 52.7'
					Boring Terminated 52.7' below the surface

* A.S.T.M. D1586

SHEET 2 OF 2

Well DW-2

Well Construction Summary

Project: Forbes Field
Location: Topeka, KS
Personnel: M. Hutson

Location or Coords: On ramp, north of row 3

Elevation: Ground Level ______
Top of Casing ______

Drilling Summary:

Total Depth 52.7'

Borehole Diameter 8" diameter to 23.1'
3.5" diameter to 52.7'

Driller Terracon Consultants

Rig CME - 55

Bit(s) 8" Roller bit
3.5' Roller bit

Drilling Fluid clean water

Surface Casing ______

Well Design:

Basis: Geologic Log ____ Geophysical Log ____

Casing String(s): C = Casing S = Screen

0 - 23.1	C	
23.1 - 52.7	Open	

Casing C1 4" dia, sch. 40, PVC

C2 ______

Screen: S1 ______

S2 ______

Centralizers ______

Filter Material ______

Cement ______

Other ______

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling				
8" hole	12/17	15:48	12/18	11:10
3.5" hole	12/26	16:30	12/26	17:50
Geophys. Logging:				
Casing:				
4"PVC	12/17	11:10	12/17	11:15
Filter Placement:				
Cementing:	12/20	11:30	12/20	11:35
Development:				
Other				

Well Development:

Developed by blowing with compressed air

Comments:

WESTON

WOODWARD

DRILLING LOG

WELL NUMBER DW-3

LOCATION On ramp, east of row 8

SURFACE ELEVATION

DRILLING COMPANY Terracon

DRILLER R. Kelly

LOG BY M. Hutson

OWNER U.S.A.F.

ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH 48.2

WATER LEVEL

DRILLING METHOD Rotary

DATE DRILLED 12/18-24/84

HELPER D. Ritter

SKETCH MAP

NOTES

logged by drilling rate and cuttings

0

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					Asphalt and Concrete 1.45'
					Dark brown, silty Clay
					17.2'
					Gray Limestone
					20'
					Gray Limestone w/shale stringers
					23.3'
					Gray Limestone
					26.6'
					Gray Shale 27.9'
					Black Shale 28.5'
					Light gray Shale 32.0'
					Gray Shale w/sand stringers

*ASTM D1586

SHEET 1 OF 2

DRILLING LOG

WELL NUMBER DW-3(cont.)
OWNER U.S.A.F.
LOCATION
ADDRESS Forbes Field Topeka, KS
TOTAL DEPTH 48.2'
SURFACE ELEVATION
WATER LEVEL
DRILLING COMPANY Terracon
DRILLING METHOD Hollow Auger
DATE DRILLED 12/18-27/84
DRILLER R. Kelly
HELPER D. Ritter
LOG BY M. Hutson / RCB

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
40					
					46.0'
					Gray Shale w/limestone stringers 48.2'
					Boring Terminated 48.2' below the surface.

* ASTM D1586

SHEET 2 OF 2

Project: Forbes Field

Location: Topeka, KS

Personnel: M. Hutson

Well: DW-3

Well Construction Summary

Location or Coords: ______

Elevation: Ground Level ______

Top of Casing ______

Drilling Summary:

Total Depth: 48.2'

Borehole Diameter: 8" to 22.2'
3.5' to 48.2'

Driller: Terracon Consultants

Rig: CME - 55

Bit(s): 8" Roller bit
3.5" Roller bit

Drilling Fluid: clean water

Surface Casing: ______

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling: 8" hole	12/18	13:53	12/18	17:16
3.5" hole	12/27	9:20	12/18	10:30
Geophys. Logging:				
Casing: 4" PVC	12/18	17:16	12/18	17:20
Filter Placement:				
Cementing:	12/20	11:40	12/20	11:52
Development:				
Other:				

Well Design:

Basis: Geologic Log X Geophysical Log ______

Casing String(s): C = Casing S = Screen

From	To	Type
0	22.2	C
22.2	48.2	Open

Casing: C1 4" dia., sch. 80, PVC

C2 ______

Screen: S1 ______

S2 ______

Centralizers ______

Filter Material ______

Cement ______

Other ______

Well Development:

Developed by blowing with compressed air

Comments:

WESTON

DRILLING LOG

WELL NUMBER DW-4

OWNER U.S.A.F.

LOCATION Northwest corner of ramp

ADDRESS Forbes Field Topeka, KS

TOTAL DEPTH

SURFACE ELEVATION

WATER LEVEL

DRILLING COMPANY Terracon

DRILLING METHOD Hollow Auger

DATE DRILLED 12/19-26/84

DRILLER R. Kelly

HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION/SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
					Asphalt and Gravel .5
					Brown Clay
					17'
					Dark gray shall 18.2'
					Limestone
					21.6'
					Light gray Shale w/some sand stringers
					37'

* ASTM D1586

SHEET 1 OF 2

WOODWARD-CLYDE CONSULTANTS

DRILLING LOG

WELL NUMBER DW-4(cont.) OWNER U.S.A.F.

LOCATION ______ ADDRESS Forbes Field

Topeka, KS

TOTAL DEPTH 48.6

SURFACE ELEVATION ______ WATER LEVEL ______

DRILLING COMPANY Terracon DRILLING METHOD Rotory DATE DRILLED 12/19-26/84

DRILLER R. Kelly HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION/SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
40					
					Dark gray Shale w/some limestone stringers
					48.6'
50					
					Boring terminated 48.6' below the surface
60					

* ASTM D1586

SHEET 2 OF 2

Well DW-4

Well Construction Summary

Location or Coords: Northwest corner of ramp

Elevation. Ground Level

Top of Casing

Location Topeka, KS

Personnel M. Hutson

Project Forbes Field

Drilling Summary:

Total Depth 48.6'

Borehole Diameter 8" to 23.5'
3.5' to 48.6'

Driller Terracon Consultants

Rig CME 55

Bit(s) 3.5" Roller bit

Drilling Fluid water

Surface Casing

Well Design:

Basis. Geologic Log ___ Geophysical Log ___

Casing String(s) C = Casing S = Screen

0	23.5	C
23.5	48.6	Open

Casing C1 4"dia, sch 80, PVC

C2

Screen: S1

S2

Centralizers

Filter Material

Cement 6:1 cement-bentonite

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling				
8"hole	12/19	9:39	12/19	11:45
3½"hole	12/26	14:45	12/26	15:20
Geophys Logging:				
Casing: 4" PVC	12/19	11:45	12/19	11:50
Filter Placement				
Cementing	12/20		12/20	
Development				
Other				

Well Development:

well developed by blowing with compressed air

Comments:

WESTON

DRILLING LOG

WELL NUMBER DW-5

OWNER U.S.A.F.

LOCATION corner of parking lot west of pumphouse

ADDRESS Forbes Field Topeka, KS

G

TOTAL DEPTH 60'

SURFACE ELEVATION

WATER LEVEL

DRILLING COMPANY Terracon

DRILLING METHOD Rotary

DATE DRILLED 12/19-26/84

DRILLER R. Kelly

HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

logged by drilling rate and cuttings

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					Topsoil .2
					Dark brown Clay 10.0'
					Weathered Shale 11.8'
					Limestone 13.4'
					Shale w/some sand stringers 29.0'
					Shale w/some limestone stringers
0					

* ASTM D1586

SHEET 1 OF 2

DRILLING LOG

WELL NUMBER DW-5 (cont.) OWNER U.S.A.F.

LOCATION ______ ADDRESS Forbes Field, Topeka, KS

TOTAL DEPTH 60'

SURFACE ELEVATION ______ WATER LEVEL: ______

DRILLING COMPANY Terracon DRILLING METHOD Rotary DATE DRILLED 12/19-20/84

DRILLER R. Kelly HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
40					Shale w/some limestone stringers
50					60'
					Boring terminated 60' below the surface

* ASTM D1586

SHEET 2 OF 2

Project Forbes Field

Location Topeka, KS

Personnel M. Hutson

Well DW-5

Well Construction Summary

Location or Coords: Corner of parking lot west of pumphouse G

Elevation. Ground Level

Top of Casing

Drilling Summary:

Total Depth 60'

Borehole Diameter 8" to 16.8'
3.5" to 60'

Driller Terracon Consultants

Rig CME -55

Bit(s) 8" roller bit
3.5" roller bit

Drilling Fluid clean water

Surface Casing

Well Design:

Basis: Geologic Log ___ Geophysical Log ___

Casing String(s) C = Casing S = Screen

0 - 16.8	C	
16.8 - 60.0	Open	

Casing C1 4" dia, sch. 80, PVC

C2

Screen S1

S2

Centralizers

Filter Material

Cement

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling				
8" hole	12/19	14:20	12/19	14:50
3½" hole	12/26	9:00	12/26	13:10
Geophys Logging				
Casing				
4" PVC	12/19	14:50	12/19	15:00
Filter Placement				
Cementing	12/20	11:00	12/20	11:05
Development				
Other				

Well Development:

Well developed by blowing with compressed air.

Comments:

WESTON

DRILLING LOG

WELL NUMBER DW-6
OWNER U.S.A.F.
LOCATION Northeast corner of Tank Farm
ADDRESS Forbes Field Topeka, KS
TOTAL DEPTH 50'
SURFACE ELEVATION
WATER LEVEL:
DRILLING COMPANY Terracon
DRILLING METHOD Rotary
DATE DRILLED 12/20-27/84
DRILLER R. Kelly
HELPER D. Ritter
LOG BY M. Hutson/RCB

SKETCH MAP

NOTES

logged by drilling rate and cuttings

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)	
					Topsoil	.3
					Brown clay	10.4
					Limestone	10.9
					Olive brown Shale	15.7
					Limestone	19.7
					Black Shale	23.0'
					Gray Shale	26.4'
					Sandstone w/some shale stringers	32.1'
					Gray sandy Shale	37.2'
					Gray sandy Shale w/some limestone stringers	

*ASTM D1586

DRILLING LOG

WELL NUMBER DW-6 (cont.)

OWNER U.S.A.F.

LOCATION

ADDRESS Forbes Field
Topeka, KS

TOTAL DEPTH 50'

SURFACE ELEVATION

WATER LEVEL

DRILLING COMPANY Terracon

DRILLING METHOD Rotary

DATE DRILLED 12/20-27/84

DRILLER R. Kelly

HELPER D. Ritter

LOG BY M. Hutson

SKETCH MAP

NOTES

DEPTH (FEET)	GRAPHIC LOG	SAMPLE NUMBER	SAMPLE TYPE	SAMPLE BLOWS*	DESCRIPTION / SOIL CLASSIFICATION (COLOR, TEXTURE, STRUCTURES)
0					
					Gray sandy shale w/some limestone stringers
					50.0
					Boring terminated 50 feet below the surface

* ASTM D1586

SHEET 2 OF 2

Well DW-6

Well Construction Summary

Location or Coords: Northwest Corner of Tank Farm

Elevation: Ground Level

Top of Casing

Project: Forbes Field

Location: Topeka, KS

Personnel: M. Hutson

Drilling Summary:

Total Depth: 50'

Borehole Diameter: 8" to 20.4'

Driller: Terracon Consultants

Rig: CME - 55

Bit(s): 8" roller bit
3.5" roller bit

Drilling Fluid: clean water

Surface Casing

Well Design:

Basis: Geologic Log x Geophysical Log

Casing String(s): C = Casing S = Screen

0 - 20.4	C	
20.4 - 50'	Open	

Casing: C1 4" dia., sch.80, PVC

C2

Screen: S1

S2

Centralizers

Filter Material

Cement

Other

Construction Time Log:

Task	Start Date	Start Time	Finish Date	Finish Time
Drilling:				
8" hole	12/20	15:00	12/20	15:45
3½" hole	12/27	14:45	12/27	15:30
Geophys. Logging:				
Casing:				
4" PVC	12/20	15:45	12/20	15:50
Filter Placement				
Cementing	12/21	8:20	12/21	8:35
Development:				
Other				

Well Development:

well developed by blowing with compressed air

Comments:

WESTON DESIGNERS CONSULTANTS

APPENDIX G

GROUND WATER FIELD SAMPLING SHEETS

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field Topeka, Ks

WELL NO.: SW-1

DATE: 1/14/85

SAMPLED BY: M. Hutson

TIME: 1:25 AM/PM

W.O. #: 0628-05-51

WEATHER: ______

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ______

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 2 in.

DEPTH TO WATER: 10.75 ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 12 ft

VOLUME IN CASING: .2 gal VOLUME EVACUATED BEFORE SAMPLING dry gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER ______

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: ______

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
SW-1	P/G	1 l.	H_2SO_4	Oil + Grease by IR
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 12° °C pH 7.2, 7.15, 7.15, 7.20 CONDUCTANCE 1240, 1120, 1250, 1260 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field, Topeka, KS.

WELL NO.: Dup SW-1

DATE: 1/14/85

SAMPLED BY: [illegible]

TIME: 1:25 AM/PM

W.O. #: [illegible]

WEATHER: ____

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ____

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ____

WELL DIAMETER: 2 in.

DEPTH TO WATER: 10.75 ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 12 ft Sampled after development

VOLUME IN CASING: .2 gal VOLUME EVACUATED BEFORE SAMPLING: dry gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER ____

SAMPLING BY: BAILING/PUMPING/OTHER ____

COMMENTS: ____

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
SW-1	P/G	1 liter	H_2SO_4	Oil & Grease by IR
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 12 °C pH 7.2, 7.15, 7.15, 7.20 CONDUCTANCE 1280, 1250, 1120, 1260 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field WELL NO.: SW-2

Topeka, Ks. DATE: 8 13 1985

SAMPLED BY: S. Ricketts, M. Hutton TIME: 12:55 AM/PM

W.O. #: 0628-03-51 WEATHER: ≈25° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ______

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 2" in.

DEPTH TO WATER: 7.63' ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 9.6' ft Sampled after well development

VOLUME IN CASING: .9 gal VOLUME EVACUATED BEFORE SAMPLING dry gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER ______

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: ______

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
SW-2	P/G	1 l,tr	H_2SO_4	O.l + Grease
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 12 °C pH 6.55 / 6.80 / 6.80 / 6.85 CONDUCTANCE 1200 / 1200 / 1200 / 1200 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field Topeka, KS WELL NO.: SW-3

DATE: 1/4/85

SAMPLED BY: M. Hudson TIME: 12:15 AM/PM

W.O. #: 0628-05-5 WEATHER: 25° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED:

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED:

WELL DIAMETER: 2 in.

DEPTH TO WATER: 9.05 ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 17.5 ft

VOLUME IN CASING: 1.7 gal VOLUME EVACUATED BEFORE SAMPLING dry gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER

SAMPLING BY: BAILING/PUMPING/OTHER

COMMENTS:

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
Sw-3	P/G	1 lit.	H_2SO_4	Oil + Grease by I.R.
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 11 °C pH 6.55 6.65 6.65 CONDUCTANCE 2100 2200 2200 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field — WELL NO.: SW-4

Topeka, Ks — DATE: 1/4/85

SAMPLED BY: M. Hutson — TIME: 1:50 AM/PM

W.O. #: 0628-05-51 WEATHER: ≈ 25° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ________

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ________

WELL DIAMETER: 2 in.

DEPTH TO WATER: 9.78 ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 11 ft

VOLUME IN CASING: ≈ .4 gal VOLUME EVACUATED BEFORE SAMPLING dry gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER ________

SAMPLING BY: BAILING/PUMPING/OTHER ________

COMMENTS: ________

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
Sw-4	P/G	1 liter	H_2SO_4	Oil + Grease
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 11 °C pH 8.05 7.95 7.9 7.9 CONDUCTANCE 2000 1900 2000 2000 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field WELL NO.: SW-5

Topeka, Kansas DATE: 1/3/85

SAMPLED BY: M Hutson TIME: 4:45 AM/PM

W.O. #: 0628-05-51 WEATHER: ≈ 20° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ______

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 2 in.

DEPTH TO WATER: 6.28' ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 7.7' ft sampled after bailing dry

VOLUME IN CASING: .3 gal VOLUME EVACUATED BEFORE SAMPLING dry ~~gal~~

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER ______

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: ______

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
SW-5	P/G	1 liter	H_2SO_4	O.l & Grease
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 11 °C pH 6.55, 6.9, 6.9, 7.0 CONDUCTANCE 840, 975, 975, 950 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field
Topeka, Ks.

WELL NO.: SW-6

DATE: 1/31/85

SAMPLED BY: M. Hutson

TIME: 11:35 AM/PM

W.O. #: 0628-05-51 WEATHER: ≈20° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED:

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED:

WELL DIAMETER: 2" in.

DEPTH TO WATER: 12.13' ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 21.35' ft

VOLUME IN CASING: 1.2 gal VOLUME EVACUATED BEFORE SAMPLING 14 gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER

SAMPLING BY: BAILING/PUMPING/OTHER

COMMENTS: Sampled following well development

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
1	P/G	1 liter	H_2SO_4	Oil & Grease by I.R
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 55F ≈ 13 °C pH 6.90 6.90 6.60 6.90 CONDUCTANCE 1906 1850 1850 1925 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field Topeka, Kansas

WELL NO.: DW-1

DATE: 1/13/85

SAMPLED BY: S. Ricketts, M. Hutson

TIME: 1:30 AM/PM

W.O. #: 0628-05-51

WEATHER: ≈25° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: not yet installed

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 4 in.

DEPTH TO WATER: 7.75' ft

REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 43' ft

VOLUME IN CASING: ______ gal

VOLUME EVACUATED BEFORE SAMPLING: dry ~~gal~~

Sampled after well development

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER compressed air

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: ______

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
DW-1	P/G	1 liter	H_2SO_4	Oil + Grease by I.R.
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 58°F/14°C °C

pH 6.70, 7.15, 7.35, 7.30

CONDUCTANCE 1375, 1400, 1400, 1400 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field WELL NO.: OW-2

Topeka, Kans. DATE: 1/3/84

SAMPLED BY: M. Hertz TIME: 4:30 AM/PM

W.O. #: [illegible] WEATHER: ≈20° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: not yet installed

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED:

WELL DIAMETER: 4 in.

DEPTH TO WATER: 13.84 ft REFERENCE CASING: PVC/STEEL

Sampled immediately after well development

TOTAL WELL DEPTH: 52' ft

VOLUME IN CASING: ____ gal VOLUME EVACUATED BEFORE SAMPLING ____ ~~gal~~

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER pressurized air

SAMPLING BY: BAILING/PUMPING/OTHER

COMMENTS:

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
OW-2	P/G	1 liter	H_2SO_4	Oil + Grease by IR
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 13° °C pH 6.8 / 7.25 / 7.3 / 7.4 CONDUCTANCE 1250 / 1300 / 1300 / 1325 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field WELL NO.: DW-3

Topeka, Ks DATE: 1/4/85

SAMPLED BY: M. [illegible] TIME: 2:30 AM/PM

W.O. #: [illegible] WEATHER: ≈20° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: not yet installed

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 4 in.

DEPTH TO WATER: 17.5' ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 48 ft

VOLUME IN CASING: 19 gal VOLUME EVACUATED BEFORE SAMPLING —— gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER compr. air

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: Sampled after well development

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
DW-3	P/G	1 lit	H_2SO_4	Oil + Grease by IR
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 13 °C pH 6.7 7.0 7.05 ~~7.15~~ CONDUCTANCE 1480 1440 1475 ~~1400~~ umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field WELL NO.: DW-4

Topeka, Ks. DATE: 1/5/85

SAMPLED BY: M. Hutson TIME: 9:10 AM/PM

W.O. #: 0629-01-01 WEATHER: ~15 Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT DAMAGED: ______

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED: ______

WELL DIAMETER: 4 in.

DEPTH TO WATER: 28.86' ft REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 48 ft

VOLUME IN CASING: 13 gal VOLUME EVACUATED BEFORE SAMPLING ______ gal

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER compressed air

SAMPLING BY: BAILING/PUMPING/OTHER ______

COMMENTS: Sampled following development — water level not yet fully recovered

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
DW-4	P/G	1 liter	H_2SO_4	Oil & Grease
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 14 °C pH 6.6, 6.7, 6.75, 6.7 CONDUCTANCE 1175, 1190, 1300, 1175 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field, Topeka, Kansas   WELL NO.: DW-5

DATE: 1/3/85

SAMPLED BY: M. Hudson   TIME: 12:13 AM/PM

W.O. #: 0628-05-51   WEATHER: ~20° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT ~~DAMAGED:~~ not yet installed

LOCKED? YES/NO

CONCRETE: INTACT DAMAGED:

WELL DIAMETER: 4" in.

DEPTH TO WATER: 8.86' ft   REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 55' ft

VOLUME IN CASING: 29.4 gal   VOLUME EVACUATED BEFORE SAMPLING ____ gal
Sampled immediately following well development

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER compressed air

SAMPLING BY: BAILING/PUMPING/OTHER

COMMENTS: sampled following well development

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
DW-5	P/G	1 liter	H_2SO_4	Oil + Grease by I.R.
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 14 °C   pH 8.95, 8.55, 8.45, 8.35   CONDUCTANCE 1810, 2100, 2300, 2400 umhos/cm

RJK 6/27/84

WESTON

FIELD SAMPLING SHEET

SITE LOCATION: Forbes Field   WELL NO.: PW-6

Topeka, Ks   DATE: 1 14 185

SAMPLED BY: M. Hutton   TIME: 11:10 AM/PM

W.O. #: 0628-01-01   WEATHER: >25° Sunny

WELL CONDITION

PROTECTIVE CASING: INTACT   DAMAGED: not yet installed

LOCKED? YES/NO

CONCRETE: INTACT   DAMAGED:

WELL DIAMETER: 4 in.

DEPTH TO WATER: 14.76' ft   REFERENCE CASING: PVC/STEEL

TOTAL WELL DEPTH: 38.5' ft

VOLUME IN CASING: 16 gal   VOLUME EVACUATED BEFORE SAMPLING ____ gal

Sampled after well development

SAMPLING

EVACUATION BY: BAILING/PUMPING/OTHER compressed air

SAMPLING BY: BAILING/PUMPING/OTHER

COMMENTS: Sampled after well development

SAMPLE BOTTLE LABEL	TYPE	VOLUME	PRESERVATIVE	PARAMETERS
Dw-1	P/G	1 liter	H_2SO_4	O.1 + Grease by I R.
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			
	P/G			

FILTERED YES/NO

FIELD MEASUREMENTS

TEMP. 12° °C   pH 8.10 7.15 7.65 7.50   CONDUCTANCE 2100 2000 2000 2000 umhos/cm

RJK 6/27/84

APPENDIX H

CHAIN OF CUSTODY DOCUMENTATION

ENVIRONMENTAL PROTECTION AGENCY
Office of Enforcement

REGION 5
230 South Dearborn Street
Chicago, Illinois 60604

CHAIN OF CUSTODY RECORD

PROJ. NO.	PROJECT NAME
	Forbes Field ANGB

SAMPLERS: (Signature) Mark A. Hister

STA. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS	Oil + Grease						REMARKS
DW-1	1/3/85	1:30p		X	DW-1	1	1					X	
DW-2	1/3/85	4:30p		X	DW-2	1	1					X	
DW-3	1/4/85	2:[illegible]p		X	DW-3	1	1					X	
DW-4	1/5/85	9:10a		X	DW-4	1	1					X	
DW-5	1/3/85	12:13p		X	DW-5	1	1					X	
DW-6	1/4/85	11:10a		X	DW-6	1	1					X	
SW-1	1/4/85	1:25p		X	SW-1	1	1					X	
SW-2	1/3/85	12:55p		X	SW-2	1	1					X	
SW-3	1/4/85	12:15p		X	SW-3	1	1					X	
SW-4	1/4/85	1:50p		X	SW-4	1	1					X	
SW-5	1/3/85	4:45p		X	SW-5	1	1					X	
SW-6	1/3/85	11:35a		X	SW-6	1	1					X	
Dup	1/4/85	1:30p		X	Dup	1	1					X	
Blank	1/4/85	6:20p		X	Blank	1	1					X	

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Mark A. Hister	1/5/85 10:30am		EMERY	1/8/85	[illegible signature]

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)

Relinquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks

Distribution: White — Accompanies Shipment; Pink — Coordinator Field Files, Yellow — Laboratory File

NVIRONMENTAL PROTECTION AGENCY
Office of Enforcement

REGION 5
230 South Dearborn Street
Chicago, Illinois 60604

CHAIN OF CUSTODY RECORD

PROJ. NO.: ?W8-05-51
PROJECT NAME: Forbes Field A.N.G.B.

AMPLERS: (Signature) Mark G. Hutar

TA. NO.	DATE	TIME	COMP.	GRAB	STATION LOCATION	NO. OF CONTAINERS	Oil & Grease by I.R.						REMARKS
2, S-3	12/13/84	3:00p		X	Boring 2, Sample 3	1	1						11-13'
W-5, S-2	12/28/84	3:[illegible]p		X	Shallow well 5 Sample 2	1	1						6.5-7' * BTEX, TOX
-4, S-1	12/27/84	1:25p		X	Shallow well 4, Sample 1	1	1						1.5-3'
-3, S-4	12/27/84	11:20a		X	Shallow well 3, Sample 4	1	1						13-16.5'
-10, S-1	12/27/84	10:40a		X	Boring 10, Sample 1	1	1						1-4'
-4, S-3	12/28/84	2:30p		X	Shallow well 4, Sample 3	1	1						8.2-11'
-1, S-2	12/28/84	8:00a		X	Shallow well 1, Sample 2	1	1						6-8'
9, S-3	12/27/84	9:55a		X	Boring 9, Sample 3	1	1						12-12.5'
3, S-2	12/13/84	4:50p		X	Boring 3, Sample 2	1	1						3-8'
4, S-1	12/14/84	8:40a		X	Boring 4, Sample 1	1	1						1.7-3.7'

linquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Mark G. Hutar	1/2/84 5:00p	Victoria K. Andrews			
linquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
linquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks	

Distribution: White — Accompanies Shipment; Pink — Coordinator Field Files; Yellow — Laboratory File

APPENDIX I

STANDARD LABORATORY ANALYTICAL PROTOCOLS

OIL AND GREASE, TOTAL RECOVERABLE

Method 413.2 (Spectrophotometric, Infrared)

STORET NO. 0056

1. Scope and Application
   - 1.1 This method includes the measurement of fluorocarbon-113 extractable matter from surface and saline waters, industrial and domestic wastes. It is applicable to the determination of hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases and related matter.
   - 1.2 The method is applicable to measurement of most light petroleum fuels, although loss of about half of any gasoline present during the extraction manipulations can be expected.
   - 1.3 The method covers the range from 0.2 to 1000 mg/l of extractable material.
   - 1.4 While this method can be used to obtain an estimate of the oil and grease that would be measured gravimetrically, in many cases the estimate more accurately describes the parameter, as it will measure volatiles more effectively and is not susceptible to interferences such as extractable sulfur. It can be used with the Petroleum Hydrocarbon procedure to obtain an oil and grease value and a petroleum hydrocarbon value on the same sample.
2. Summary of Method
   - 2.1 The sample is acidified to a low pH (<2) and extracted with fluorocarbon-113. The oil and grease is determined by comparison of the infrared absorbance of the sample extract with standards.
3. Definitions
   - 3.1 The definition of oil and grease is based on the procedure used. The source of the oil and/or grease, and the presence of extractable non-oily matter will influence the material measured and interpretation of results.
4. Sampling and Storage
   - 4.1 A representative sample of 1 liter volume should be collected in a glass bottle. If analysis is to be delayed for more than a few hours, the sample is preserved by the addition of 5 ml HCl (6.1) at the time of collection and refrigerated at 4°C.
   - 4.2 Because losses of grease will occur on sampling equipment, the collection of a composite sample is impractical. Individual portions collected at prescribed time intervals must be analyzed separately to obtain the average concentration over an extended period.
5. Apparatus
   - 5.1 Separatory funnel, 2000 ml, with Teflon stopcock.
   - 5.2 Infrared spectrophotometer, scanning. Non-scanning instruments may also be used but can be subject to positive interferences in complex chemical wastewaters.
   - 5.3 Cells, 10 mm, 50 mm, and 100 mm path length, sodium chloride or infrared grade glass.
   - 5.4 Filter paper, Whatman No. 40, 11 cm.

Issued 1974
Editorial revision 1978

APPENDIX J

Raw Laboratory Data

WESTON

DATE OF FINAL REPORT: 28 January 1985

FORBES FIELD AIR NATIONAL GUARD BASE
FINAL REPORT
OIL AND GREASE BY I.R.: SOILS

DATE SAMPLES COLLECTED: 12/13/84, 12/14/84, 12/28/84, 12/29/84

SAMPLES COLLECTED BY: Mark Hutson

SAMPLES RECEIVED BY LABORATORY: 1/3/85

R.F.W. NO.	SAMPLE DESCRIPTION	OIL AND GREASE, mg/g
8501-011-0010	B-2, S-3	51
-0020	SW-5, S-2	829
-0030	SW-4, S-1	30
-0040	SW-3, S-4	38
-0050	B-10, S-1	686
-0060	SW-4, S-3	31
-0070	SW-1, S-2	38
-0080	B-9, S-3	25
-0090	B-3, S-2	50
-0100	B-4, S-1	36

OIL AND GREASE BY I.R.: WATER

DATE SAMPLES COLLECTED: 1/3, 1/4/85

SAMPLES COLLECTED BY: Mark Hutson

SAMPLES RECEIVED BY LABORATORY: 1/8/85

R.F.W. NO.	SAMPLE DESCRIPTION	OIL AND GREASE, mg/L
8501-035-0010	DW-1	0.71
-0020	DW-2	<0.10
-0030	DW-3	<0.10
-0040	DW-4	<0.10
-0050	DW-5	1.39
-0060	DW-6	0.17
-0070	SW-1	1.09
-0080	SW-2	1.75
-0090	SW-3	0.23

WESTON

DATE: 28 January 1985

FORBES A.N.G.B. (CON'T)

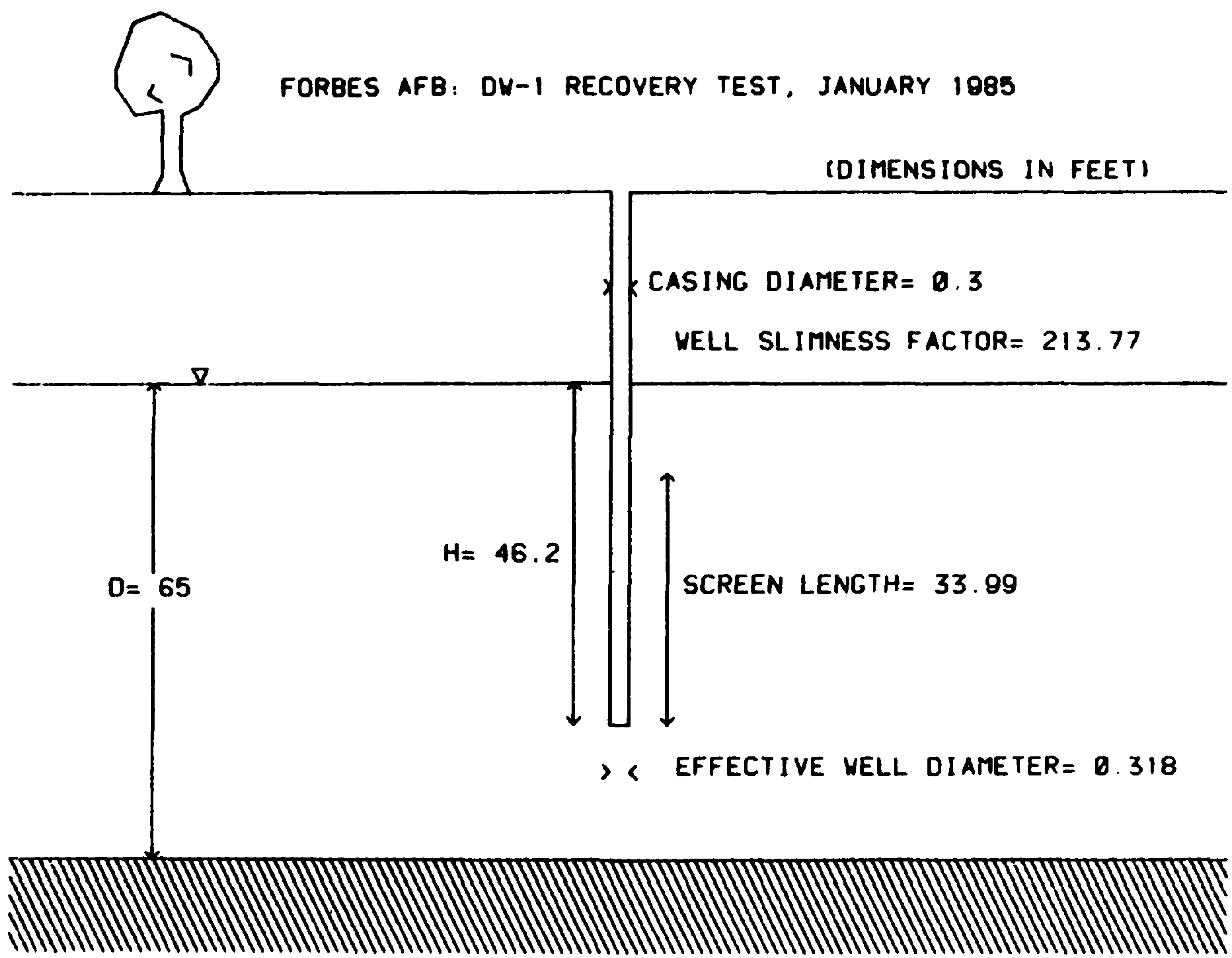
R.F.W. NO.	SAMPLE DESCRIPTION	OIL AND GREASE, mg/L
8501-035-0100	SW-4	0.45
-0110	SW-5	3970
-0120	SW-6	2.03
-0130	DUPLICATE	3.27 SW-1
-0140	FIELD BLANK	<0.10

APPROVED BY: Earl M. Hansen

Earl M. Hansen, Ph.D.
Director
Analytical Laboratory

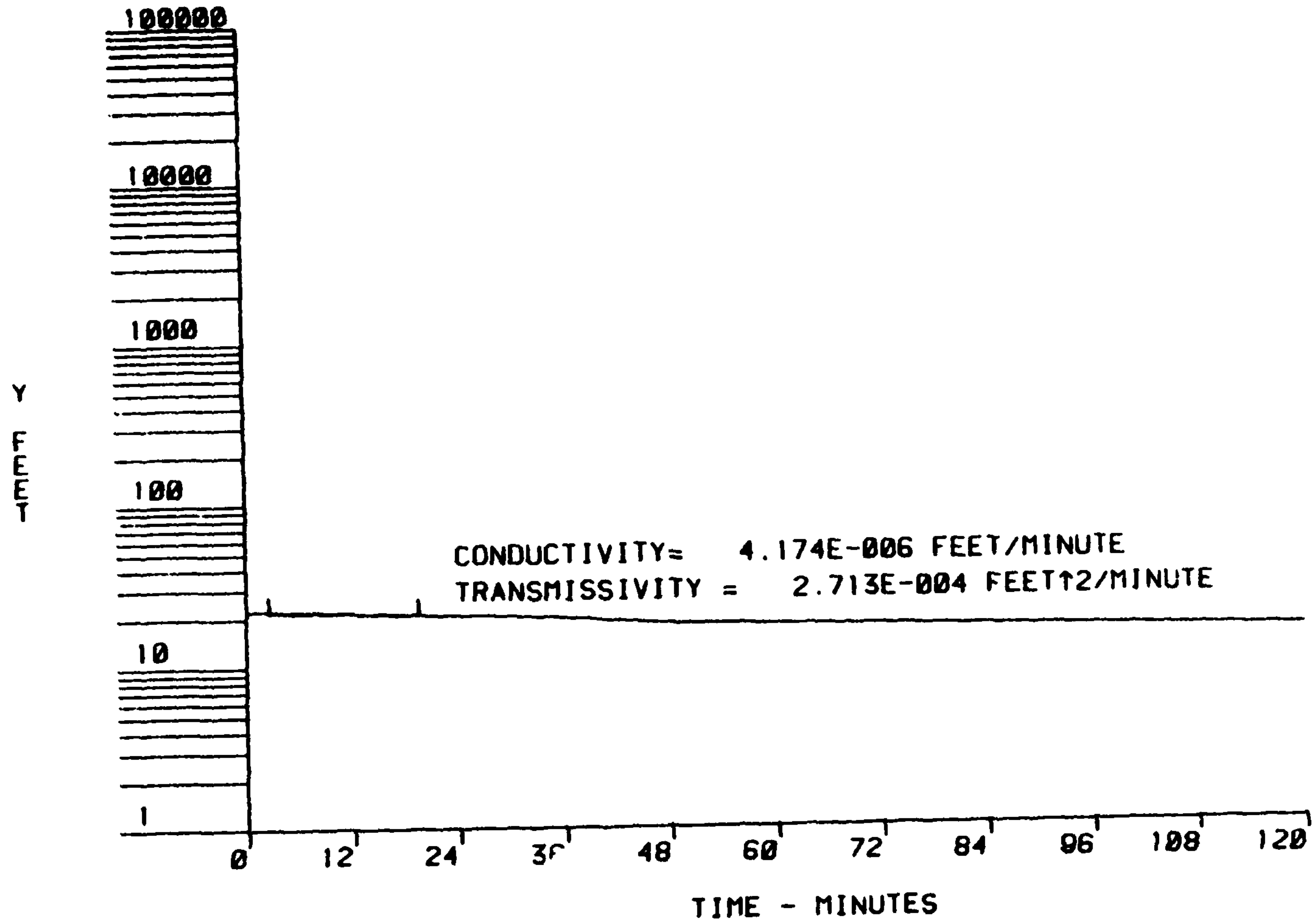
APPENDIX K

BAILDOWN TEST DATA AND ANALYTICAL REFERENCE

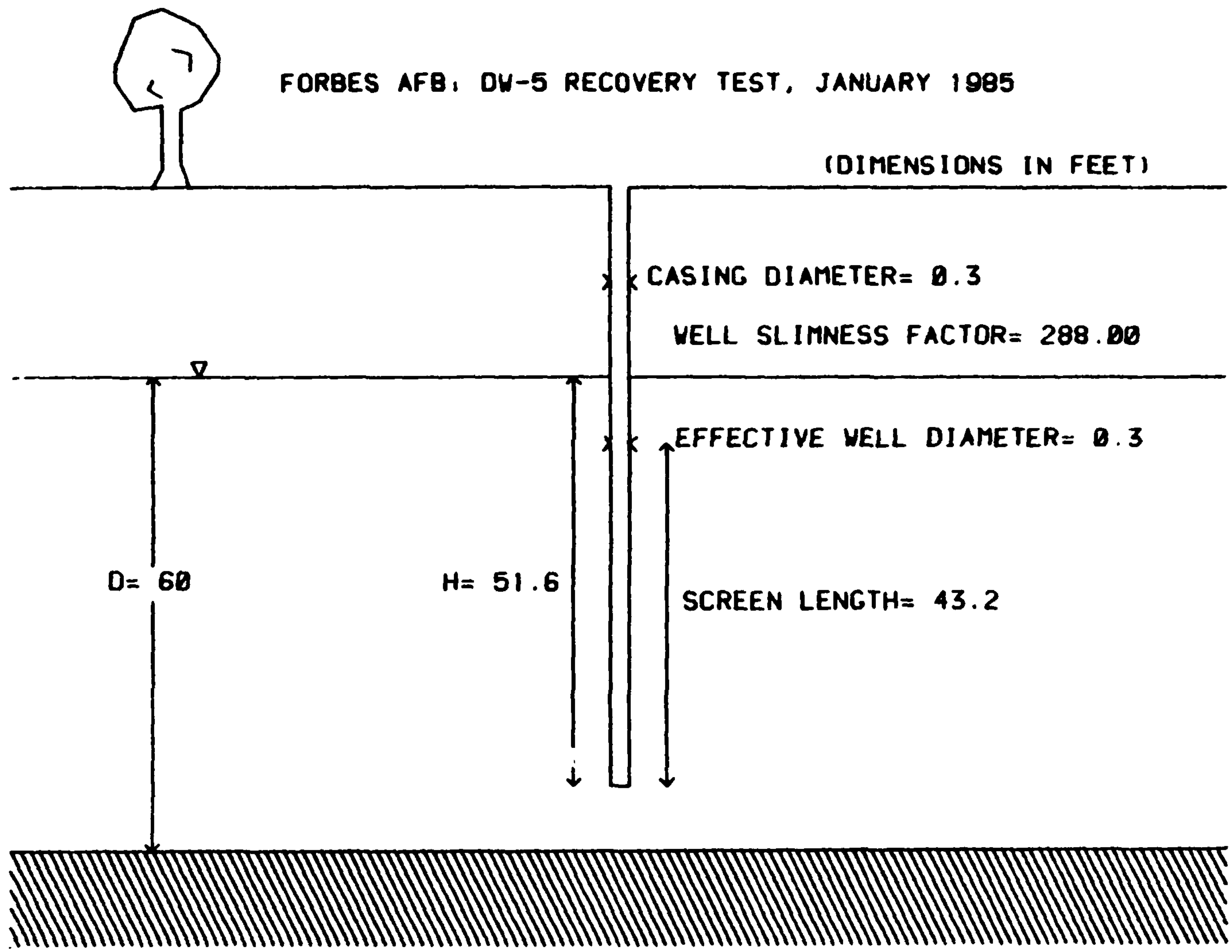

FORBES AFB: DW-1 RECOVERY TEST, JANUARY 1985
(DIMENSIONS IN FEET)
CASING DIAMETER= 0.3
WELL SLIMNESS FACTOR= 213.77
H= 46.2
D= 65
SCREEN LENGTH= 33.99
EFFECTIVE WELL DIAMETER= 0.318

FORBES AFB: DW-1 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	22.02	2.5
2	21.97	3.5
3	21.84	4.5
4	21.72	5.5
5	21.7	6.5
6	21.63	7.5
7	21.6	8.5
8	21.54	9.5
9	21.47	10.5
10	21.41	11.5
11	21.37	12.5
12	21.28	13.5
13	21.11	15.5
14	21	17.5
15	20.87	19.5
16	20.68	22.5
17	20.56	24.5
18	20.31	29.5
19	20.19	30.5
20	20.13	31.5
21	20.02	33.5
22	18	48.5
23	15.71	120

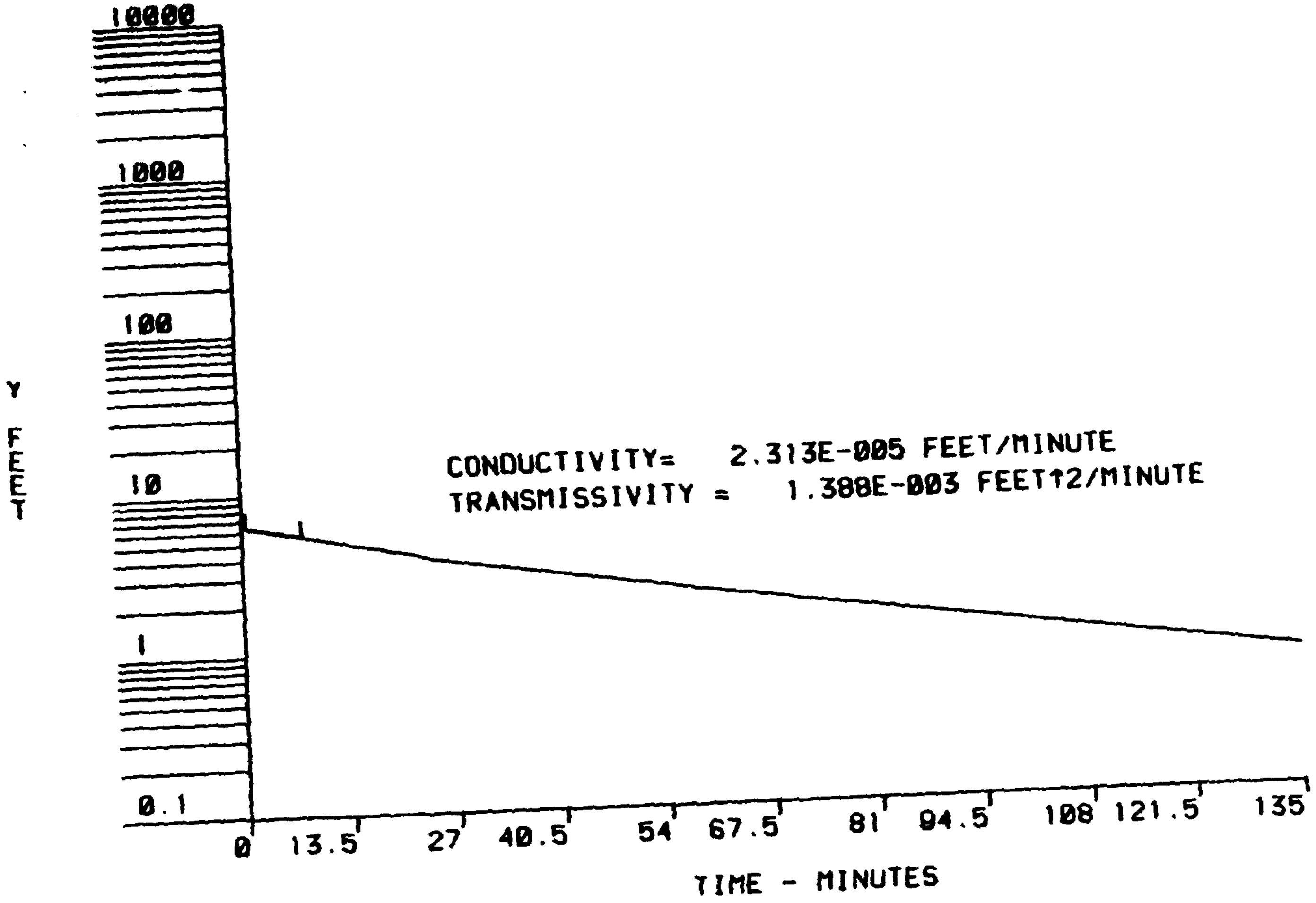


FORBES AFB: DW-1 RECOVERY TEST, JANUARY 1985


FORBES AFB: DW-5 RECOVERY TEST, JANUARY 1985
(DIMENSIONS IN FEET)
CASING DIAMETER= 0.3
WELL SLIMNESS FACTOR= 288.00
EFFECTIVE WELL DIAMETER= 0.3
D= 60
H= 51.6
SCREEN LENGTH= 43.2

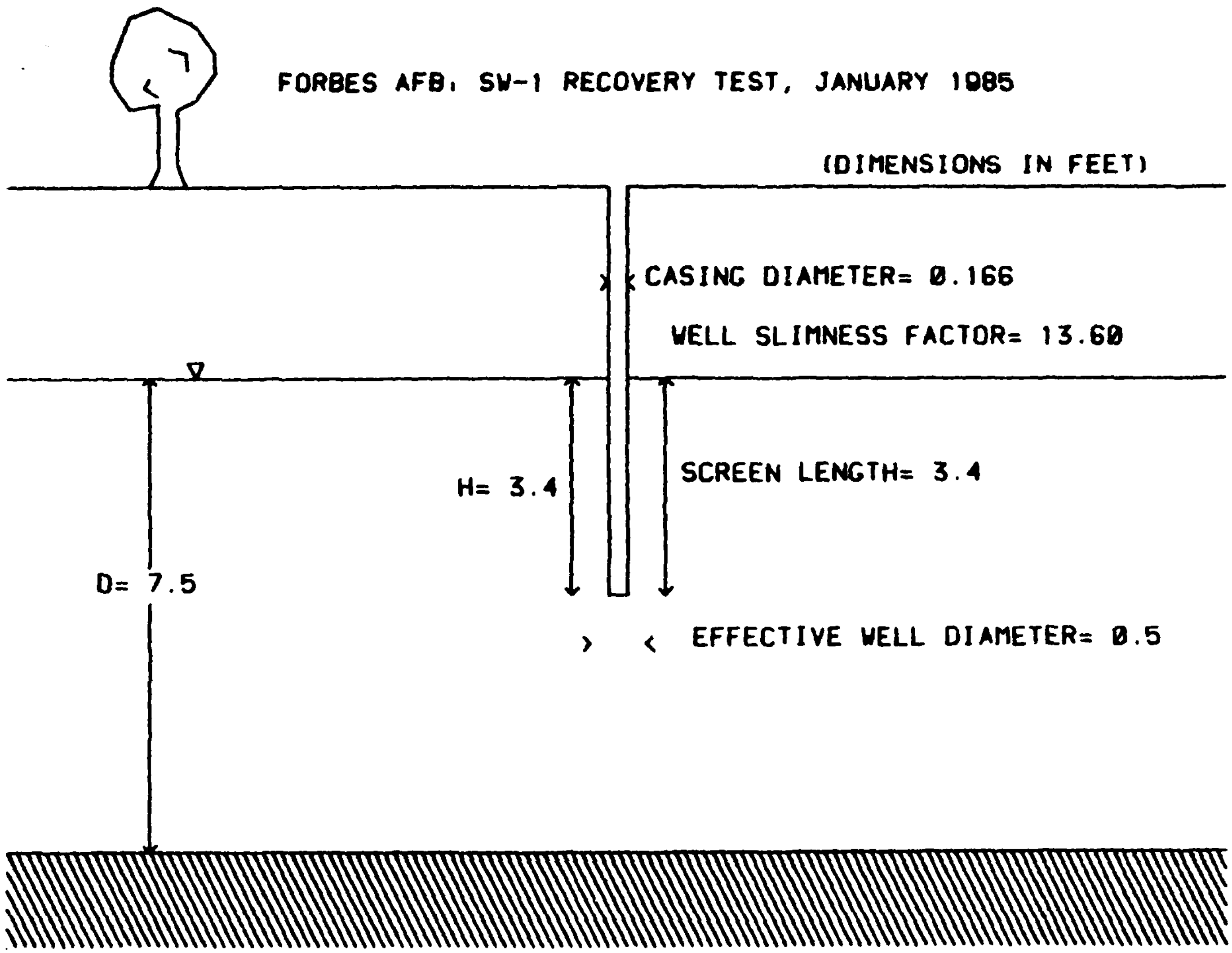
FORBES AFB: DW-5 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	6.44	0.5
2	6.3	1.5
3	6.19	2.5
4	6.05	3.5
5	5.88	4.5
6	5.75	5.5
7	5.57	7.5
8	5.41	8.5
9	4.21	21
10	3.79	25
11	2.84	43
12	2.1	62
13	0.73	135



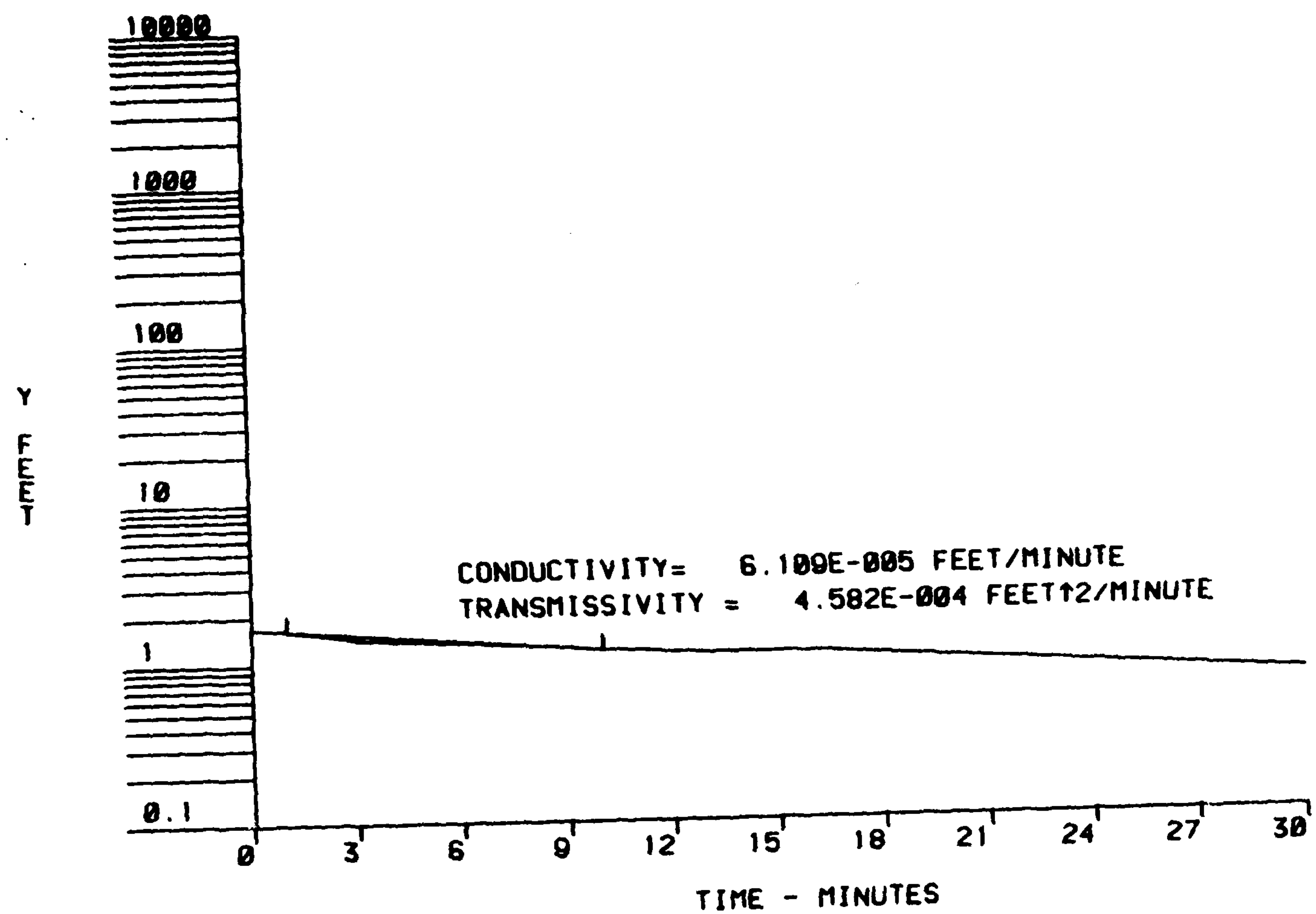
FORBES AFB, DW-5 RECOVERY TEST, JANUARY 1985

FORBES AFB, SW-1 RECOVERY TEST, JANUARY 1985

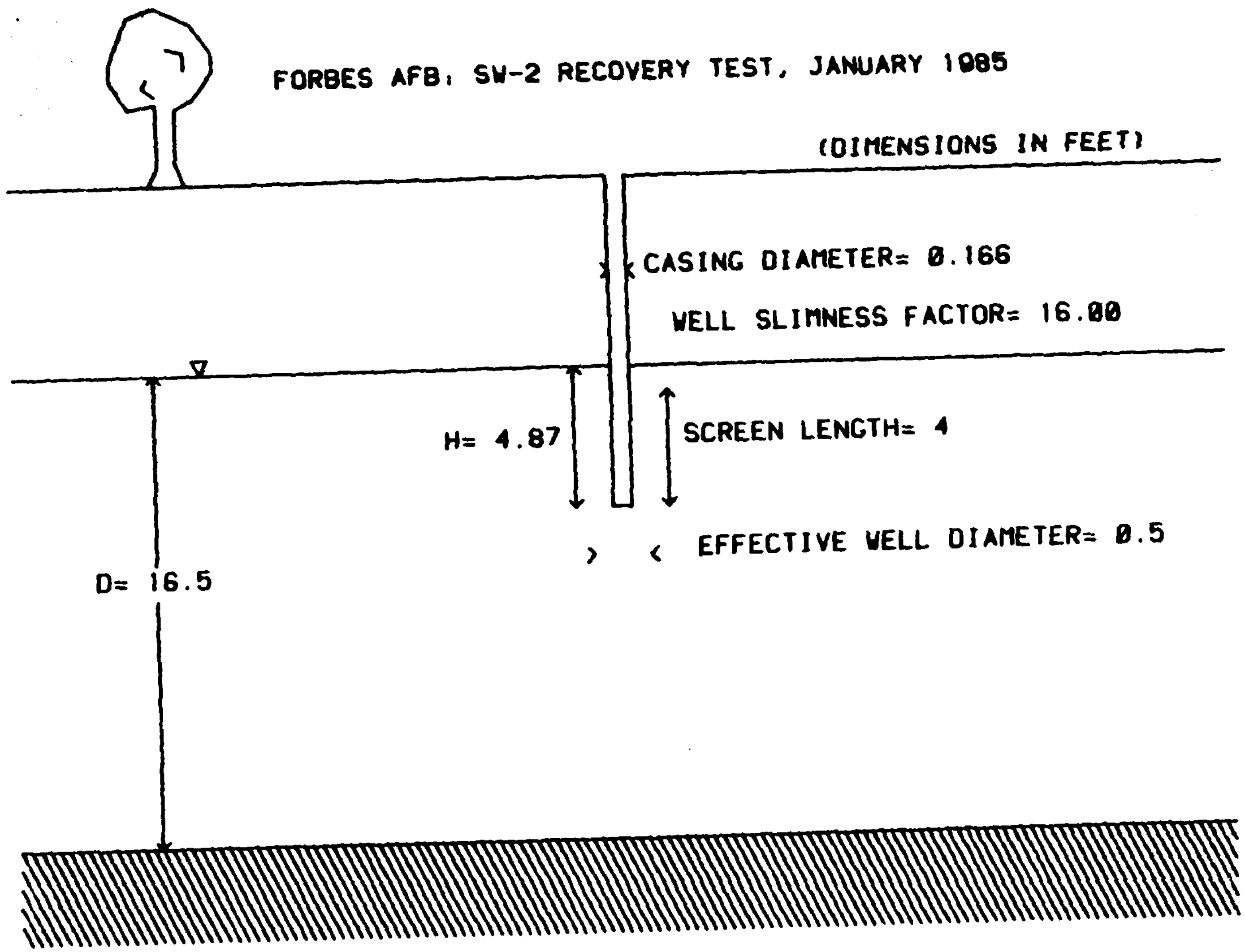


FORBES AFB, SW-1 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	1.63	1
2	1.55	2
3	1.42	3
4	1.38	4
5	1.35	5
6	1.33	6
7	1.29	7
8	1.26	8
9	1.22	9
10	1.17	10
11	1.16	11
12	1.12	12
13	1.1	13
14	1.09	16
15	0.73	30

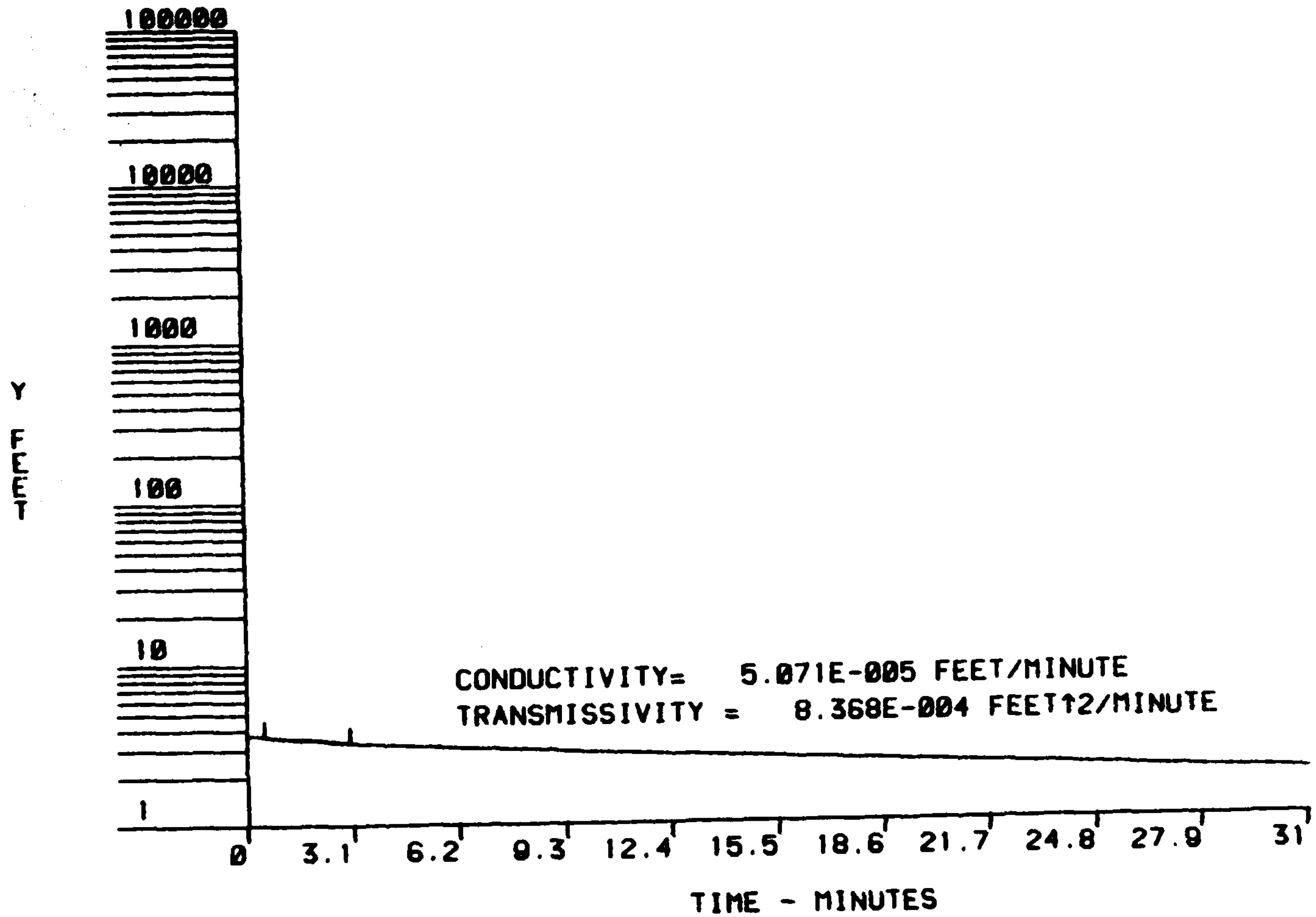


FORBES AFB: SW-1 RECOVERY TEST, JANUARY 1985

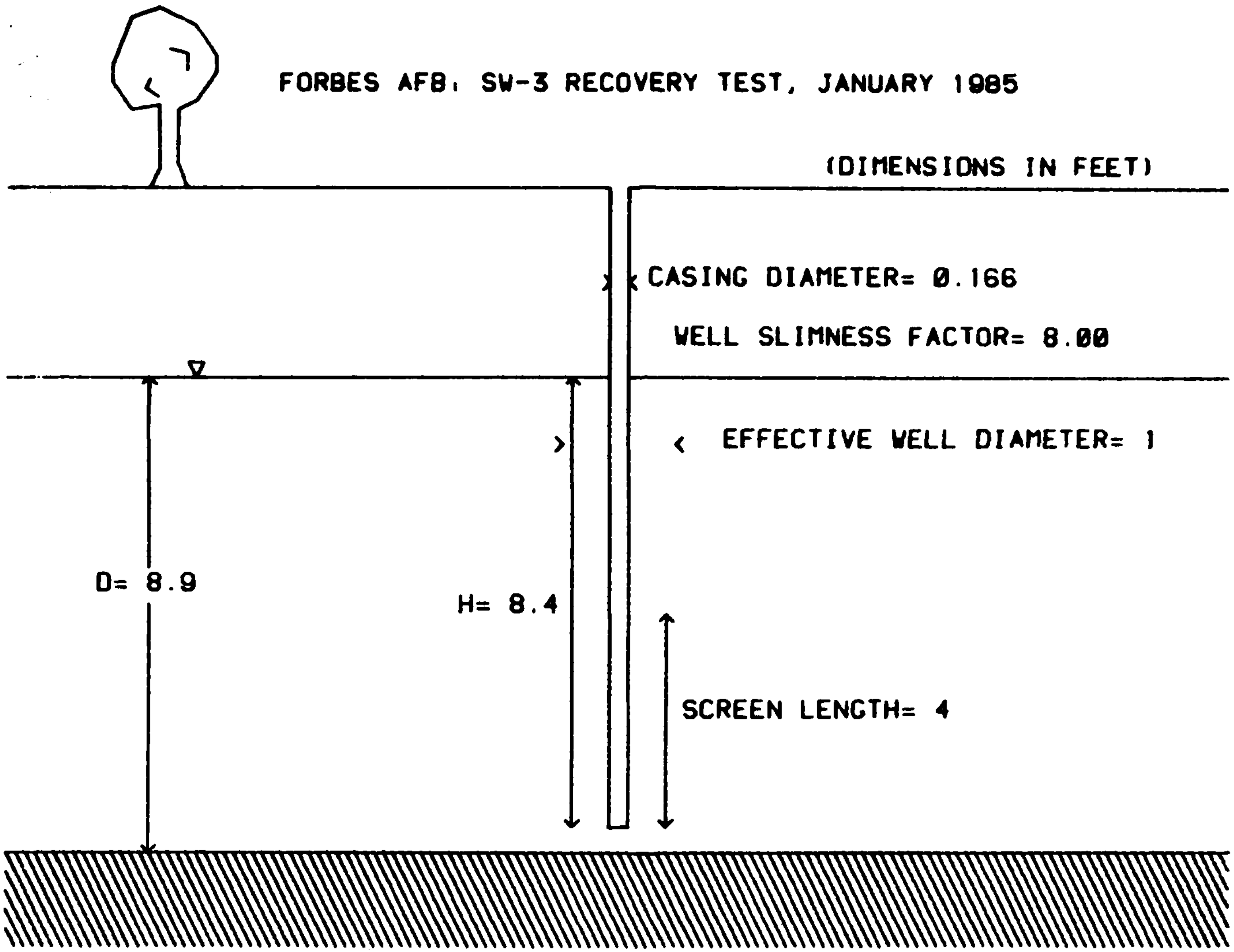

FORBES AFB: SW-2 RECOVERY TEST, JANUARY 1985
(DIMENSIONS IN FEET)
CASING DIAMETER= 0.166
WELL SLIMNESS FACTOR= 16.00
H= 4.87
SCREEN LENGTH= 4
EFFECTIVE WELL DIAMETER= 0.5
D= 16.5

FORBES AFB: SW-2 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	3.59	0.5
2	3.54	1
3	3.47	1.5
4	3.42	2
5	3.34	2.5
6	3.3	3
7	3.22	3.5
8	3.19	4
9	3.16	4.5
10	3.12	5
11	3.05	6
12	2.99	7
13	2.94	8
14	2.89	9
15	2.81	10
16	1.91	31

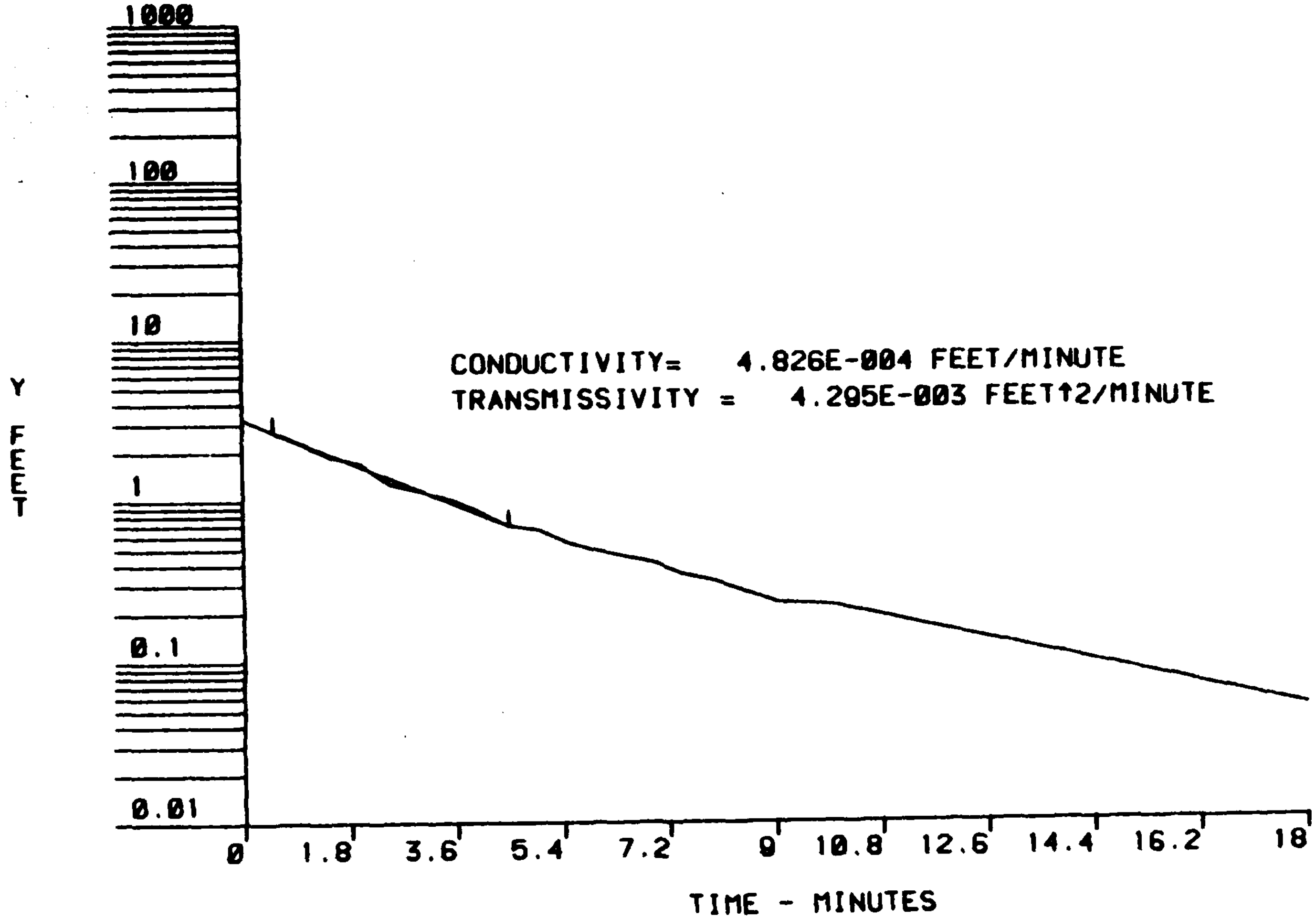


FORBES AFB: SW-2 RECOVERY TEST, JANUARY 1985

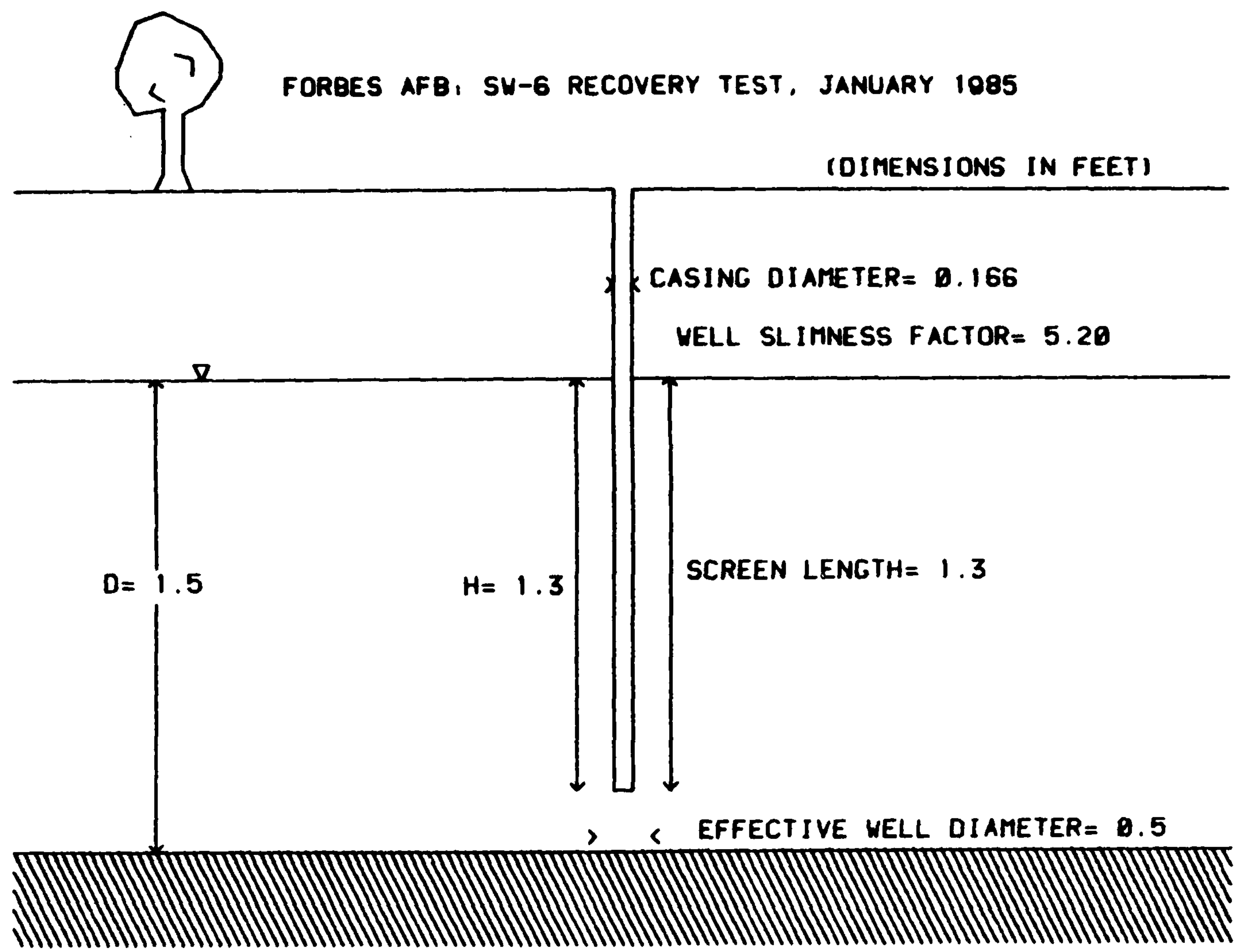

FORBES AFB: SW-3 RECOVERY TEST, JANUARY 1985
(DIMENSIONS IN FEET)
CASING DIAMETER= 0.166
WELL SLIMNESS FACTOR= 8.00
EFFECTIVE WELL DIAMETER= 1
D= 8.9
H= 8.4
SCREEN LENGTH= 4

FORBES AFB: SW-3 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	2.7	0.5
2	1.87	1.5
3	1.69	2
4	1.26	2.5
5	1.14	3
6	1.01	3.5
7	0.85	4
8	0.69	4.5
9	0.65	5
10	0.54	5.5
11	0.48	6
12	0.44	6.5
13	0.4	7
14	0.34	7.5
15	0.31	8
16	0.23	9
17	0.22	10
18	0.05	18

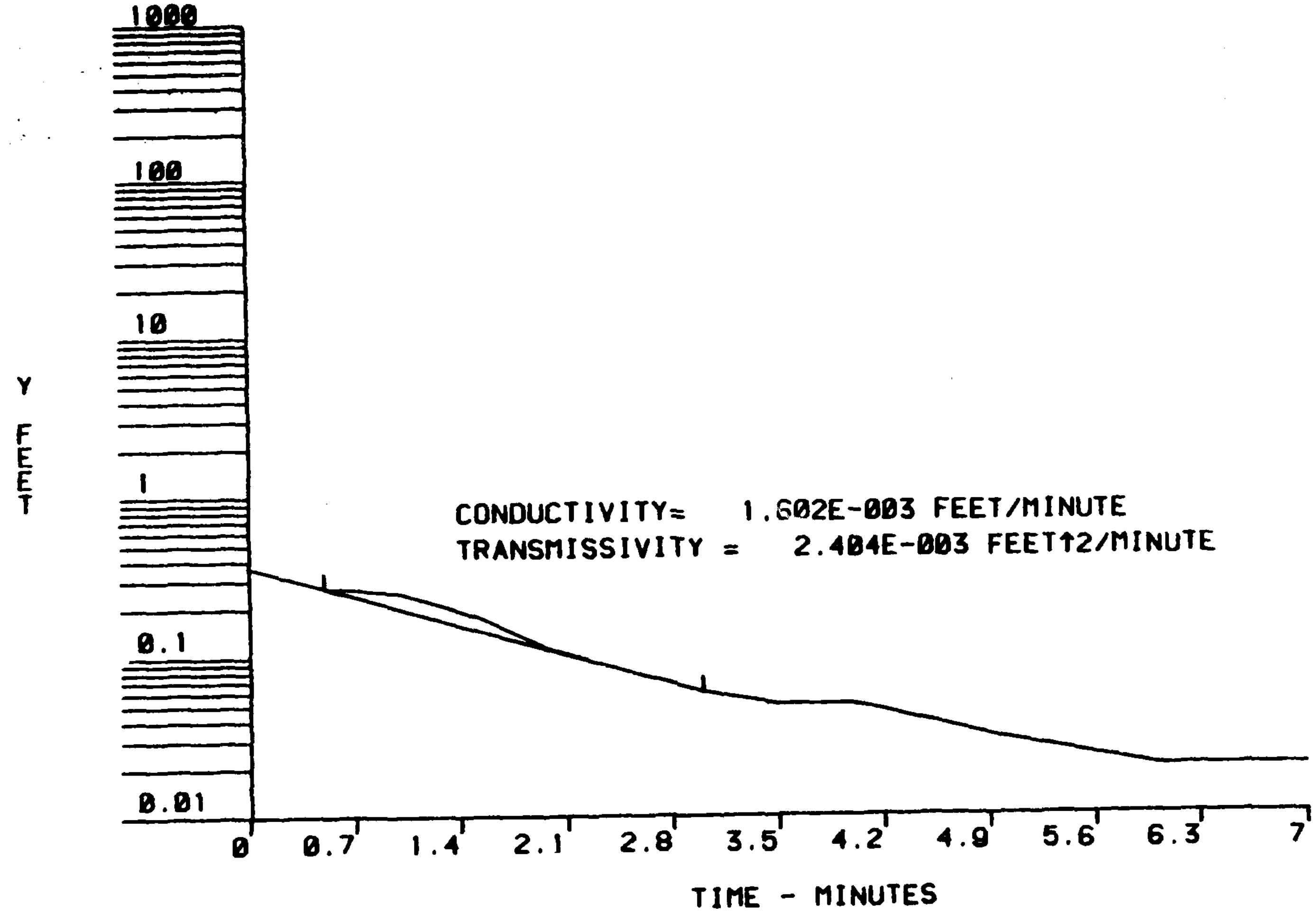


FORBES AFB, SW-3 RECOVERY TEST, JANUARY 1985


FORBES AFB: SW-6 RECOVERY TEST, JANUARY 1985
(DIMENSIONS IN FEET)
CASING DIAMETER= 0.166
WELL SLIMNESS FACTOR= 5.20
D= 1.5
H= 1.3
SCREEN LENGTH= 1.3
EFFECTIVE WELL DIAMETER= 0.5

FORBES AFB, SW-6 RECOVERY TEST, JANUARY 1985

	'Y' READINGS	TIME (MINUTES)
1	0.27	0.5
2	0.25	1
3	0.18	1.5
4	0.11	2
5	0.08	2.5
6	0.06	3
7	0.05	3.5
8	0.05	4
9	0.03	5
10	0.02	6
11	0.02	7



FORBES AFB, SW-6 RECOVERY TEST, JANUARY 1985

A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells

HERMAN BOUWER AND R. C. RICE

U.S. Water Conservation Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Phoenix, Arizona 85040

A procedure is presented for calculating the hydraulic conductivity of an aquifer near a well from the rate of rise of the water level in the well after a certain volume of water is suddenly removed. The calculation is based on the Thiem equation of steady state flow to a well. The effective radius R_e over which the head difference between the equilibrium water table in the aquifer and the water level in the well is dissipated was evaluated with a resistance network analog for a wide range of system geometries. An empirical equation relating R_e to the geometry of the well and aquifer was derived. The technique is applicable to completely or partially penetrating wells in unconfined aquifers. It can also be used for confined aquifers that receive water from the upper confining layer. The method's results are compatible with those obtained by other techniques for overlapping geometries.

With the slug test the hydraulic conductivity or transmissibility of an aquifer is determined from the rate of rise of the water level in a well after a certain volume or 'slug' of water is suddenly removed from the well. The slug test is simpler and quicker than the Theis pumping test because observation wells and pumping the well are not needed. With the slug test the portion of the aquifer 'sampled' for hydraulic conductivity is smaller than that for the pumping test even though with the latter, most of the head loss also occurs within a relatively small distance of the pumped well and the resulting transmissibility primarily reflects the aquifer conditions near the pumped well.

Essentially instantaneous lowering of the water level in a well can be achieved by quickly removing water with a bailer or by partially or completely submerging an object in the water, letting the water level reach equilibrium, and then quickly removing the object. If the aquifer is very permeable, the water level in the well may rise very rapidly. Such rapid rises can be measured with sensitive pressure transducers and fast-response strip chart recorders or x-y plotters. Also it may be possible to isolate portions of the perforated or screened section of the well with special packers for the slug test. This not only reduces the inflow and hence the rate of rise of the water level in the well, but it also makes it possible to determine the vertical distribution of the hydraulic conductivity. Special packer techniques may have to be developed to obtain a good seal, especially for rough casings or perforations. Effective sealing may be achieved with relatively long sections of inflatable stoppers or tubing. The use of long sections of these materials would also reduce leakage flow from the rest of the well to the isolated section between packers. This flow can occur through gravel envelopes or other permeable zones surrounding the casing. Sections of inflatable tubing may have to be long enough to block off the entire part of the well not used for the slug test. High inflation pressures should be used to minimize volume changes in the tubing due to changing water pressures in the isolated section when the head is lowered.

So far, solutions for the slug test have been developed only for completely penetrating wells in confined aquifers. *Cooper et al.* [1967] derived an equation for the rise or fall of the water level in a well after sudden lowering or raising, respectively. Their equation was based on nonsteady flow to a pumped, completely penetrating well, and the solution was expressed as a series of 'type curves' against which observed rates of water level rises were matched. Values for the transmissibility and storage coefficient were then evaluated from the curve parameter and horizontal-scale position of the type curve showing the best fit with the experimental data. *Skibitzke* [1958] developed an equation for calculating transmissibility from the recovery of the water level in a well that was repeatedly bailed. The technique is limited to wells in confined aquifers with sufficiently shallow water levels to permit short time intervals between bailing cycles [*Lohman*, 1972].

To use the slug test for partially penetrating or partially perforated wells in confined or unconfined aquifers, some solutions developed for the auger hole and piezometer techniques to measure soil hydraulic conductivity [*Bouwer and Jackson*, 1974] may be employed. However, the geometry of most groundwater wells is outside the range in geometry covered by the existing equations or tables for the auger hole or piezometer methods. For this reason, theory and equations are presented in this paper for slug tests on partially or completely penetrating wells in unconfined aquifers for a wide range of geometry conditions. The wells may be partially or completely perforated, screened, or otherwise open along their periphery. While the solutions are developed for unconfined aquifers, they may also be used for slug tests on wells in confined aquifers if water enters the aquifer from the upper confining layer through compression or leakage.

THEORY

Geometry and symbols of a well in an unconfined aquifer are shown in Figure 1. For the slug test the water level in the well is suddenly lowered, and the rate of rise of the water level is measured. The flow into the well at a particular value of y can be calculated by modifying the Thiem equation to

$$Q = 2\pi KL \frac{y}{\ln (R_e/r_w)} \qquad (1)$$

where Q is the flow into the well (length³/time), K is the hydraulic conductivity of the aquifer (length/time), L is the height of the portion of well through which water enters (height of screen or perforated zone or of uncased portion of well), y is the vertical distance between water level in well and equilibrium water table in aquifer, R_e is the effective radius over which y is dissipated, and r_w is the horizontal distance

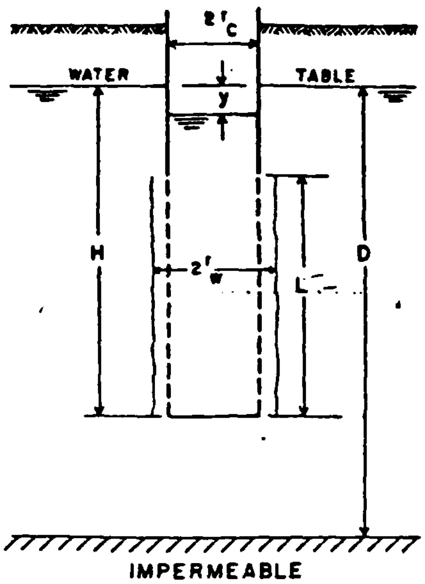


Fig. 1. Geometry and symbols of a partially penetrating, partially perforated well in unconfined aquifer with gravel pack or developed zone around perforated section.

from well center to original aquifer (well radius or radius of casing plus thickness of gravel envelope or developed zone).

The terms L, y, R_e, and r_w are all expressed in units of length. The effective radius R_e is the equivalent radial distance over which the head loss y is dissipated in the flow system. The value of R_e depends on the geometry of the flow system, and it was determined for different values of H, L, D, and r_w (Figure 1) with a resistance network analog, as will be discussed in the next section. Equation (1) is based on the assumptions that (1) drawdown of the water table around the well is negligible, (2) flow above the water table (in the capillary fringe) can be ignored, (3) head losses as water enters the well (well losses) are negligible, and (4) the aquifer is homogeneous and isotropic. These are the usual assumptions in the development of equations for pumped hole techniques [*Bouwer and Jackson*, 1974, and references therein].

The value of r_w in (1) represents the radial distance between the undisturbed aquifer and the well center. Thus r_w should include gravel envelopes or 'developed' zones if they are much more permeable than the aquifer itself (Figure 1).

The rate of rise, dy/dt, of the water level in the well after suddenly removing a slug of water can be related to the inflow Q by the equation

$$dy/dt = -Q/\pi r_c^2 \tag{2}$$

where πr_c^2 is the cross-sectional area of the well where the water level is rising. The minus sign in (2) is introduced because y decreases as t increases.

The term r_c is the inside radius of the casing if the water level is above the perforated or otherwise open portion of the well. If the water level is rising in the perforated section of the well, allowance should be made for the porosity outside the well casing if the hydraulic conductivity of the gravel envelope or developed zone is much higher than that of the aquifer. In that case the (open) porosity in the permeable zone must be included in the cross-sectional area of the well. For example, if the radius of the perforated casing is 20 cm and the casing is surrounded by a 10-cm permeable gravel envelope with a porosity of 30%, r_c should be taken as $[20^2 + 0.30(30^2 - 20^2)]^{1/2} = 23.5$ cm to obtain the cross-sectional area of the well that relates Q to dy/dt. The value of r_w for this well section is 30 cm.

Combining (1) and (2) yields

$$\frac{1}{y}\,dy = -\frac{2KL}{r_c^2 \ln (R_e/r_w)}\,dt \tag{3}$$

which can be integrated to

$$\ln y = -\frac{2KLt}{r_c^2 \ln (R_e/r_w)} + \text{constant} \tag{4}$$

Applying this equation between limits y_0 at $t = 0$ and y_t at t and solving for K yield

$$K = \frac{r_c^2 \ln (R_e/r_w)}{2L}\,\frac{1}{t}\,\ln \frac{y_0}{y_t} \tag{5}$$

This equation enables K to be calculated from the rise of the water level in the well after suddenly removing a slug of water from the well. Since K, r_c, r_w, R_e, and L in (5) are constants, $(1/t) \ln y_0/y_t$ must also be constant. Thus field data should yield a straight line when they are plotted as $\ln y_t$ versus t. The term $(1/t) \ln y_0/y_t$ in (5) is then obtained from the best-fitting straight line in a plot of $\ln y$ versus t (see the example). The value of $\ln R_e/r_w$ is dependent on H, D, L, and r_w and can be evaluated from the analog results presented in the next section. The transmissibility T of the aquifer is calculated by multiplying (5) by the thickness D of the aquifer or

$$T = \frac{Dr_c^2 \ln (R_e/r_w)}{2L}\,\frac{1}{t}\,\ln \frac{y_0}{y_t} \tag{6}$$

This equation is based on the assumption that the aquifer is uniform with depth.

Equations (5) and (6) are dimensionally correct. Thus K and T are expressed in the same units as the length and time parameters in the equations.

EVALUATION OF R_e

Values of R_e, expressed as $\ln R_e/r_w$, were determined with an electrical resistance network analog for different values of r_w, L, H, and D (Figure 1), using the same assumptions as those for (1). An axisymmetric sector of 1 rad was simulated by a network of electrical resistors. The vertical distance between the nodes was constant, but the radial distance between nodes increased with increasing distance from the center line (Figure 2). This yielded a network with the highest node density near the well, where the head loss was greatest, and a decreasing node density toward the outer reaches of the system. For a more detailed discussion of graded networks for representing axisymmetric flow systems, see *Liebmann* [1950] and *Bouwer* [1960].

The radial extent of the medium represented on the analog was more than 60,000 times the largest r_w value used in the analyses. Thus the radial extent of the analog system was essentially infinite, as evidenced by the fact that a reduction in radial extent by several nodes did not have a measurable effect on the observed value of R_e.

The value of R_e for an infinitely deep aquifer ($D = \infty$) was determined by simulating an impermeable and then an infinitely permeable layer at a certain value of D. If this value of D is taken to be sufficiently large, the flow in the system when the layer at D is taken as being impermeable is only slightly

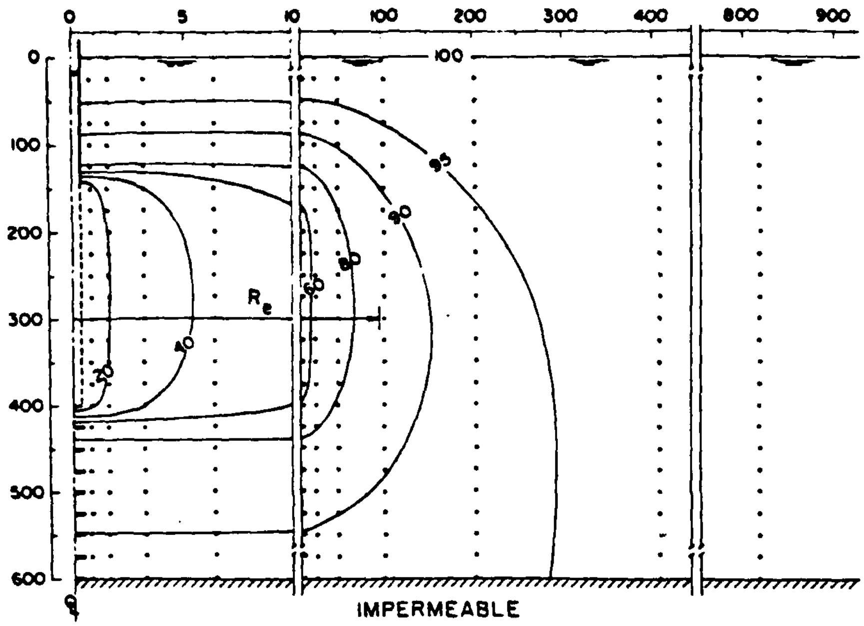


Fig. 2. Node arrangement (dots) for resistance network analog and potential distribution (indicated as percentages on equipotentials) for system with $L/r_w = 625$, $H/r_w = 1000$, and $D/r_w = 1500$. The numbers on the left and at the top of the figure are arbitrary length units (note breaks in horizontal scale).

less than the flow when the layer is taken as being infinitely permeable. The average of the two flows can then be taken as a good estimate of the flow that would occur if the aquifer were represented on the analog as being uniform to infinite depth [*Bouwer*, 1967]. This average flow was used to calculate R_e for $D = \infty$.

The analog analyses were performed by simulating a system with certain values of r_w, H, and D. The electrical current entering the 'well' was then measured for different values of L, ranging from near H to near 0. This was repeated for other values of r_w, H, and D. The condition where $L = H$ could not be simulated on the analog because it would mean a short between the water table as the source and the well as the sink. The electrical current flow in the analog was converted to volume per day, and $\ln R_e/r_w$ was evaluated with (1) for each combination of r_w, H, L, and D used in the analog.

For a given geometry described by r_w, H, and D, the current flow Q_t into the simulated well varied essentially linearly with L and could be described by the equation

$$Q_t = mL + n \tag{7}$$

Because of the linearity between Q_t and L the results of the analyses could be extrapolated to the condition $L = H$. The values of m in (7) appeared to vary inversely with $\ln H/r_w$. The values of n varied approximately linearly with $\ln [(D - H)/r_w]$, the slope A and intercept B in these relations being a function of L/r_w. This enabled the derivation of the following empirical equation relating $\ln R_e/r_w$ to the geometry of the system:

$$\ln \frac{R_e}{r_w} = \left[\frac{1.1}{\ln (H/r_w)} + \frac{A + B \ln [(D - H)/r_w]}{L/r_w}\right]^{-1} \tag{8}$$

In this equation, A and B are dimensionless coefficients that are functions of L/r_w, as shown in Figure 3. If $D >> H$, an increase in D has no measurable effect on $\ln R_e/r_w$. The analog results indicated that the effective upper limit of $\ln [(D - H)/r_w]$ is 6. Thus if D is considered infinity or $(D - H)/r_w$ is so large that $\ln [(D - H)/r_w]$ is greater than 6, a value of 6 should still be used for the term $\ln [(D - H)/r_w]$ in (8).

If $D = H$, the term $\ln [(D - H)/r_w]$ in (8) cannot be used. The analog results indicated that for this condition, which is the case of a fully penetrating well, (8) should be modified to

$$\ln R_e/r_w = \left(\frac{1.1}{\ln (H/r_w)} + \frac{C}{L/r_w}\right)^{-1} \tag{9}$$

where C is a dimensionless parameter that is a function of L/r_w as shown in Figure 3.

Equations (8) and (9) yield values of $\ln R_e/r_w$ that are within 10% of the actual value as evaluated by analog if $L > 0.4H$ and within 25% if $L << H$ (for example, $L = 0.1H$).

The analog analyses were performed for wells that were closed at the bottom. Occasionally, however, wells with open bottoms were also simulated. The flow through the bottom appeared to be negligible for all values of r_w and L used in the analyses. If L is not much greater than r_w (for example, $L/r_w << 4$), the system geometry approaches that of a piezometer cavity [*Bouwer and Jackson*, 1974], in which case the bottom flow can be significant. Equations (8) and (9) can also be used to evaluate $\ln R_e/r_w$ if a portion of the perforated or otherwise open part of the well is isolated with packers for the slug test.

Equipotentials for the flow system around a partially penetrating, partially perforated well in an unconfined aquifer after lowering the water level in the well are shown in Figure 2. The numbers along the symmetry axis and the water table represent arbitrary length units. The numbers on the equipotentials indicate the potential as a percentage of the total head difference between the water table (100%) and the open portion of the well (0%) shown as a dashed line.

The value of R_e for the case in Figure 2 is 96.7 length units. As shown in the figure, this corresponds approximately to the

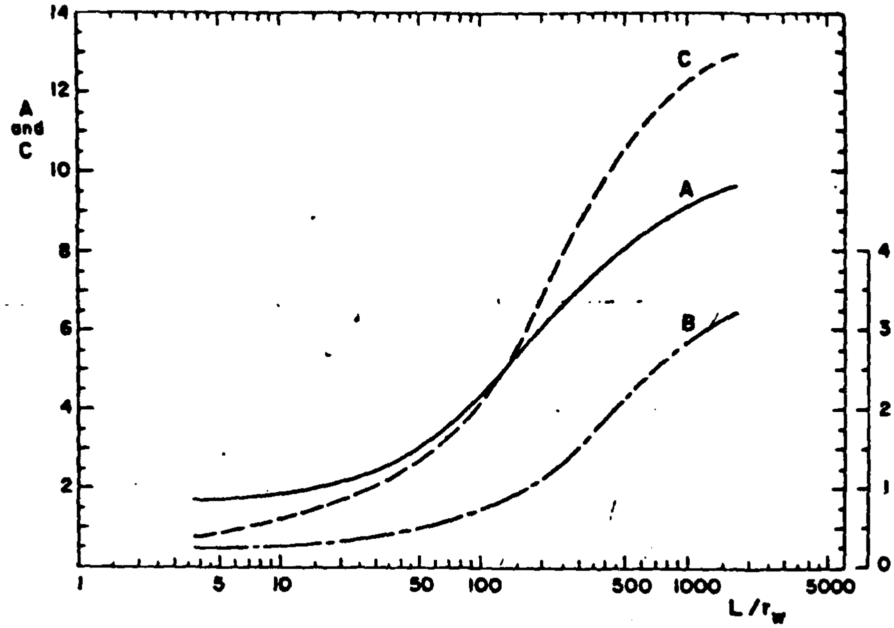


Fig. 3. Curves relating coefficients A, B, and C to L/r_w.

85% equipotential when R_e is laterally extended from the center of the open portion of the well. Thus most of the head loss in the flow system occurs in a cylinder with radius R_e, which is indicative of the horizontal extent of the portion of the aquifer sampled for K or T. The vertical extent is somewhat greater than L, as indicated by, for example, the 80% equipotential in Figure 2.

To estimate the rate of rise of the water level in a well after it is suddenly lowered, (5) can be written as

$$t = \frac{r_c^2}{2KL} \ln \frac{R_e}{r_w} \ln \frac{y_0}{y_t} \qquad (10)$$

By taking $y_t = 0.9y_0$, (10) reduces to

$$t_{90\%} = 0.0527 \frac{r_c^2}{KL} \ln \frac{R_e}{r_w} \qquad (11)$$

where $t_{90\%}$ is the time that it takes for the water level to rise 90% of the distance to the equilibrium level. By assuming a permeable aquifer with $K = 30$ m/day, a well with $r_c = 0.2$ m and $L = 10$ m, and $\ln(R_e/r_w) = 3$, (11) yields $t_{90\%} = 1.82$ s. Thus if y_0 is taken as 30 cm, it takes 1.8 s for the water level to rise 27 cm, another 1.8 s for the next 2.7 cm (90% of the remaining 3 cm), and another 1.8 s for the next 0.27 cm, or a total of 5.4 s for a rise of 29.97 cm. Measurement of this fast rise requires a sensitive and accurate transducer and a fast-response recorder. The rate of rise can be reduced by allowing groundwater to enter through only a portion of the open section of the well, as can be accomplished with packers.

For a moderately permeable aquifer with, for example, $K = 1$ m/day, a well with $r_c = 0.1$ m and $L = 20$ m, and $\ln(R_e/r_w) = 5$, (11) yields $t = 11.4$ s. In this case, it would take the water level 22.8 s to rise from 30 cm to 0.3 cm below static level.

Example

A slug test was performed on a cased well in the alluvial deposits of the Salt River bed west of Phoenix, Arizona. The well, known as the east well, is located about 20 m east of six rapid infiltration basins for groundwater recharge with sewage effluent [*Bouwer*, 1970]. The static water table was at a depth of 3m, $D = 80$ m, $H = 5.5$ m, $L = 4.56$ m, $r_c = 0.076$ m, and r_w was taken as 0.12 m to allow for development of the aquifer around the perforated portion of the casing. A Statham PM131TC pressure transducer was suspended about 1 m below the static water level in the well (when trade names and company names are included, they are for the convenience of the reader and do not imply preferential endorsement of a particular product or company over others by the U.S. Department of Agriculture). A solid cylinder with a volume equivalent to a 0.32-m change in water level in the well was also placed below the water level. When the water level had returned to equilibrium, the cylinder was quickly removed. The transducer output, recorded on a Sargent millivolt recorder, yielded the y-t relationship shown in Figure 4 with y plotted on a logarithmic scale. The straight-line portion is the valid part of the readings. The actual y_0 value of 0.29 m indicated by the straight line is close to the theoretical value of 0.32 m calculated from the displacement of the submerged cylinder.

Extending the straight line in Figure 4 shows that for the arbitrarily selected t value of 20 s, $y = 0.0025$ m. Thus $(1/t) \ln y_0/y_t = 0.238$ s^{-1}. The value of $L/r_w = 38$, for which Figure 3 yields $A = 2.6$ and $B = 0.42$. Substituting these values into (8) and using the maximum value of 6 for $\ln[(D - H)/r_w]$ (since $\ln[(D - H)/r_w]$ for the well exceeds 6) yield $\ln(R_e/r_w) = 2.37$. Equation (5) then gives $K = 0.00036$ m/s $= 31$ m/day. This value agrees with K values of 10 and 53 m/day obtained previously with the tube method on two nearby observation wells [*Bouwer*, 1970]. These K values were essentially point measurements on the aquifer immediately around the well bottoms, which were at depths of 9.1 and 6.1 m, respectively.

Comparisons

Piezometer method. The geometry to which (8) and (9) and the coefficients in Figure 3 apply overlaps the geometry of the

:zometer method at the lower values of L/r_w. With the :zometer method a cavity is augered out in the soil below a :zometer tube. The water level in the tube is abruptly wered, and K of the soil around the cavity is calculated from e rate of rise of the water level in the tube [*Bouwer and ickson*, 1974]. The equation for K is

$$K = \frac{\pi r_w^2}{A_Y} \frac{1}{t} \ln \frac{y_0}{y_t} \qquad (12)$$

here A_Y is a geometry factor with dimension of length. Values of A_Y were evaluated with an electrolytic tank analog by *'oungs* [1968], whose results were expressed in tabular form as $_Y/r_w$ for different values of L/r_w (ranging between 0 and 8), $H - L)/r_w$, and $(D - H)/r_w$.

Taking a hypothetical case where $L/r_w = 8$, $H/r_w = 12$, and $)/r_w = 16$, K calculated with (5) is 18% below K calculated ith (12). This is more than the 10% error normally expected with (8) and (9) for the L/H value of 0.67 in this case. The arger discrepancy may be due to the difference in method-logy, or to the fact that the L/r_w value is close to the lower imit of the range covered on the resistance network analog.

An approximate equation for calculating K with the pie-ometer method was presented by *Hvorslev* [1951]. The equation, which is based on the assumptions of an ellipsoidal cavity or well screen and infinite vertical extent (upward and downward) of the flow system, contains a term $[1 + (L/2r_w)^2]^{1/2}$. For most well-slug-test geometries, $L/2r_w$ will be sufficiently large to permit replacement of this term by $L/2r_w$. In that case, however, Hvorslev's equation for Q yields $R_e = L$, which is not true. In reality, R_e is considerably less than L. For example, if $L = 40$ m, $r_w = 0.4$ m, $H = 80$ m, and $D = \infty$, (8) shows that $R_e = 11.9$ m, which is much less than the value of 40 m indicated by Hvorslev's equation. However, since the calculation of K is based on $\ln (R_e/r_w)$ as shown by (5), the error in K is less than the error in R_e (i.e., 36 and 236%, respectively, in this case).

If, for the above example, the top of the well screen or cavity had been taken at the same level as the water table ($H = 40$ m), R_e would have been 8.6 m and Hvorslev's equation would have yielded a K value that is 50% higher than K given by (5). The larger error is probably due to Hvorslev's assumption of infinite vertical (upward) extent of the flow system, which is not met when the cavity is immediately below the water table. Using Hvorslev's equation for cavities immediately below a confining layer would increase the error to 73%, but this, of course, is due to the fact that a water table is not a solid boundary. Hvorslev's equation for the confining layer case can be shown to yield $R_e = 2L$.

Auger hole method. The analog analyses for (8) and (9) and Figure 3 were performed for $L < H$, because short circuiting between the water table and the well prevented simulation of the case where $L = H$. If the analog results are extrapolated to $L = H$, however, the geometry of the system in Figure 1 becomes similar to that of the auger hole technique, for which a number of equations and graphs have been developed to calculate K from the rise of the water level in the well [*Bouwer and Jackson*, 1974]. *Boast and Kirkham* [1971], for example, developed the equation

$$K = C_{BK} \frac{\Delta y}{\Delta t} \qquad (13)$$

where C_{BK} was determined mathematically and expressed in tabular form for various values of L/r_w, $(D - H)/r_w$, and y_w/H. Since the rate of rise of the water level in the hole after the removal of a slug of water decreases with decreasing y, $\Delta y/\Delta t$ is not a constant and the value of K obtained with this procedure depends on the magnitude of Δy used in the field measurements. The general rule is that Δy should be relatively small.

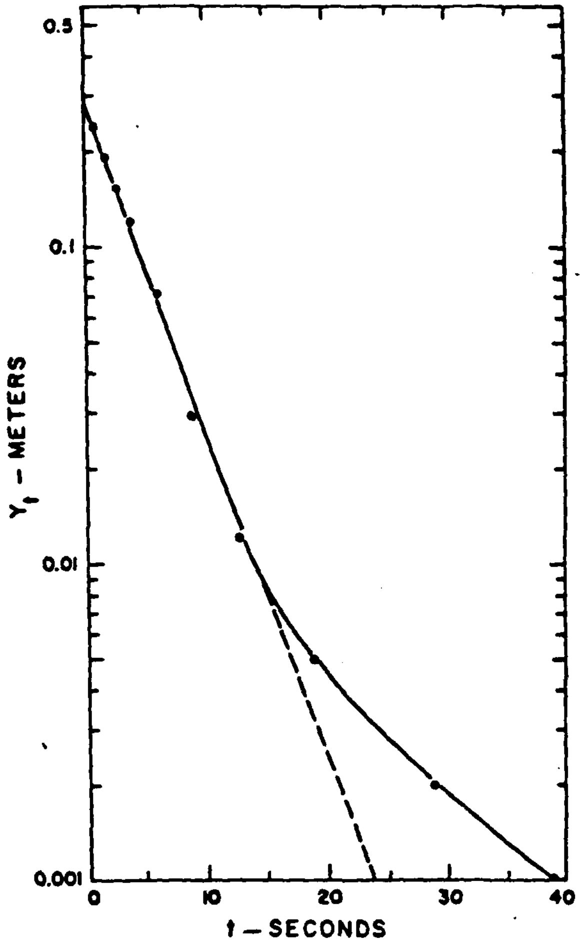


Fig. 4. Plot of y versus t for slug test on east well.

Taking a hypothetical case where $y_0 = 2.5$ m, $y_t = 2.4$ m, $\Delta t = 10$ s, $L = H = 5$ m, $D = 6$ m, and $r_w = 0.1$ m, (5) yields a K value that is 36% lower than K calculated with (13). However, if y_t is taken as 0.5 m, which should give $\Delta t = 394$ s according to the theory that $(1/t) \ln y_0/y_t$ is constant, the K value yielded by (5) is 26% higher than K obtained with (13). If y_t is taken as 0.9 m, (5) and (13) give identical results.

Slug test on wells in confined aquifers. The confined aquifer for which the slug test by *Cooper et al.* [1967] was developed is an aquifer with an internal water source, for example, recharge through aquitards or compression of confining layers or other material. This situation is similar to that of the unconfined aquifer presented in this paper because the water table is considered horizontal, like the upper boundary of a confined aquifer, and the water table is a plane source. Thus K or T calculated with (5) or (6) should be of the same order as K calculated with the procedure of *Cooper et al.* [1967], which involves plotting the rise of the water level in the well and finding the best fit on a family of type curves. *Cooper et al.* [1967] presented an example of the calculation of T for a well with $r_c = r_w = 0.076$ m and $L = 98$ m. The resulting value of T was 45.8 m^2/day. Values of D and H for this well were not given. However, since the well was 122 m deep and completely penetrating (at least theoretically), D and H must have been between 98 and 122 m. Assuming that both D and H were 100 m, (6) yields $T = 62.8$ m^2/day, which is compatible with T obtained by Cooper et al.

CONCLUSIONS

The hydraulic conductivity of an aquifer near a well can be calculated from the rise of the water level in the well after a slug of water is suddenly removed. The calculation is based on the Thiem equation, using an effective radius R_e for the distance over which the head difference between the equilibrium water table in the aquifer and the water level in the well is dissipated. Values of R_e were evaluated by electrical resistance network analog. An empirical equation was then developed to relate R_e to the geometry of the system. This equation is accurate to within 10–25%, depending on how much of the well below the water table is perforated or otherwise open. The technique is applicable to partially or completely penetrating wells in unconfined aquifers. It can also be used to estimate the hydraulic conductivity of confined aquifers that receive water from the upper confining layer through recharge or compression.

The vertical distance between the rising water level in the well and the equilibrium water table in the aquifer must yield a straight line when it is plotted on a logarithmic scale against time. This can be used to check the validity of field measurements and to obtain the best-fitting line for calculating the hydraulic conductivity. Permeable aquifers produce rapidly rising water levels that can be measured with fast-response pressure transducers and strip chart recorders or x-y plotters. The portion of the aquifer sampled for hydraulic conductivity with the slug test is approximately a cylinder with radius R_e and a height somewhat larger than the perforated or otherwise open section of the well.

Hydraulic conductivity values obtained with the proposed slug test are compatible with those yielded by the auger hole and piezometer techniques where the geometries of the systems overlap, and by a slug test for completely penetrating wells in confined aquifers.

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APPENDIX L

Quality Assurance Plan

WESTON

QUALITY ASSURANCE PLAN

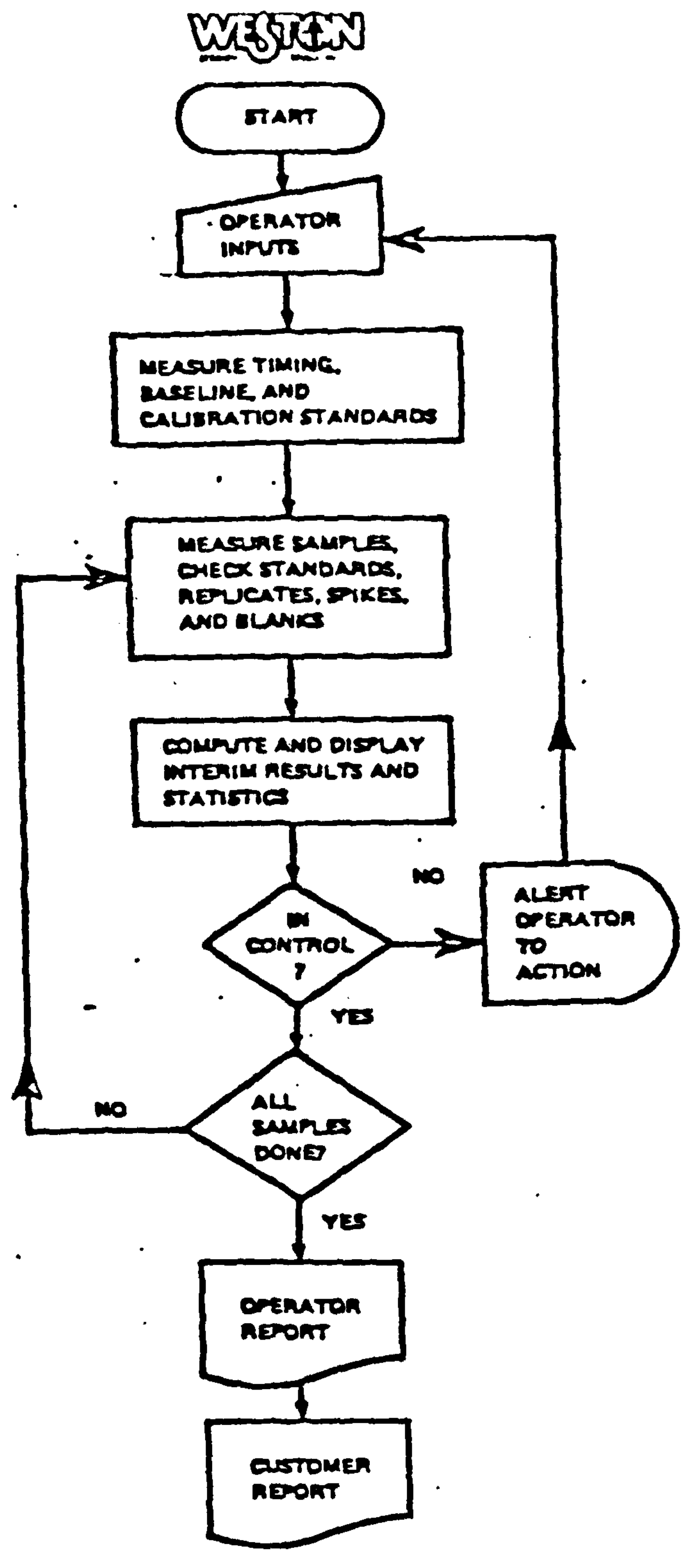
WESTON Analytical Services enforces a rigid QA/QC program toward maintenance of validity and reliability of all analytical data. The Laboratory QA/QC Manual (Table of Contents thereof is Attachment No. 1 to this appendix) outlines the specifics of the QA/QC plan. This plan is patterned after the EPA Handbook for Analytical Quality Control in Water and Wastewater Laboratories (EPA-600/4-79-019, March 1979), augmented by general applicable experience and interaction with the QA/QC plan of the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). All methods and procedures followed by WESTOn are either USEPA or ASTM-approved. Any variations from such procedures, regardless of cause, are documented by the responsible analyst(s) and are documentable, and, literature-traceable. A general review of this QA/QC plan is in the following paragraphs.

Although specific QA/QC measures for each method are designated in WESTON's Laboratory Quality Assurance Manual, the general QA/QC program normally includes:

- o EPA-acceptable sample preparation and analytical methods.
- o Instrument calibration via use of Standard Analytical Reference Materials (SARMS).
- o Regular equipment maintenance and servicing.
- o Use of SARMS and QA/QC samples (spikes, laboratory blanks, replicates, and splits) to ascertain overall precision.
- o Statistical evaluation of data to delineate acceptable limits.
- o Documentation of system/operator performance.
- o Suitable chain-of-custody procedures.
- o Maintenance and archiving of all records, charts, and logs generated in the above.
- o Proper reporting.

Acceptable analyses at WESTON's Analytical Laboratory Services include, but are not limited to, the above.

In general, WESTON's QA/QC sequence follows the following diagram (Figure E-1). Documentation (as available from instrument recordings and technicians' notebooks) is sufficient to validate each step in the sequence.



Flow Chart of the Sequence of Events during a Controlled Series of Laboratory Measurements.

CONTAINER PREPARATION

Another consideration in this, or any, analytical project is that of sample container preparation. Accordingly, all appropriate sample bottles shall be cleaned in a manner mandated by the U.S. EPA to insure maximal cleanliness (and minimal contamination) before the containers go to the field. Sufficient bottles to accommodate both laboratory and field blank requirements will be prepared in a single batch mode for each sampling requirement.

VERIFICATION/VALIDATION

In the laboratory, the analytical scheme begins with initial verification, which is comprised of:

- Lab Blanks - To insure that no background level of specific analytes is introduced by laboratory procedures.

- Standard Analytical Reference Materials (SARMS) - To determine the accuracy and precision of procedures.

- Spikes - To determine the percent recovery of analyte(s).

If the laboratory QA/QC program is extended to the field, it includes a fifth item:

- Field Blanks - To provide a check on contamination of containers and/or preservatives and to establish "practical" detection limits.

WESTON has used all of the above in this project. All data resulting from these verification media have been archived for future reference, retrieval, or processing.

WESTON

DATA HANDLING - LABORATORY

Use of any analytical data should be preceded by an assessment of its quality. The assessment should be based on accuracy, precision, completeness, representativeness, and comparability. These criteria are, in turn, assessed as follows:

- Accuracy - Is it acceptable for the planned use? QA/QC shall measure the accuracy of all data.
- Precision - Is it acceptable for the planned use? QA/QC shall reflect the reproducibility of the measurements.
- Completeness - Are the data sufficient for the planned use? QA/QC shall identify the quantity of data needed to match the goals.
- Representativeness -Do the data accurately reflect actual site conditions, sampling procedures, and analytical method? QA/QC shall ensure this.
- Comparability - Is the report self-consistent in format, units, and standardization of methods used to generate it? QA/QC shall ensure this.

Additionally, statistical methods outlined in the QA/QC program have been applicable to data evaluation.

The Laboratory Supervisor and the Laboratory QA/QC Officer have been responsible for the evaluation of the above criteria and for enforcement of analytical protocols that will necessarily lead to acceptable data quality. The signature of the Supervisor and QA/QC Officer accompany each laboratory analytical report and serve to ensure the overall validity of the reported data.

WESTON

SAMPLE PLAN/LOG

Normal protocol demands client-and /or site-specific logging of all sample batches delivered to WESTON. Basic information -- such as client name, address, etc.; client phone number; reporting/invoicing instructions; site descriptions; and parameter-specifications and total requirements -- is initiated here. Additionally, sample storage/disposal instructions as well as turnaround requirements and sample collection requirements are addressed at this point.

The appropriate number of method blanks is also logged at this point, and in-house chain-of-custody documentation is initiated here.

SAMPLE RESULTS

WESTON's analytical protocols generally require five-point calibration curve <u>plus</u> a reagent blank s the basis for quantification analytes from a linear calibration curve. (A three-point plus blank curve vs. the original five point one is acceptable if it falls within the QA/QC requirements of $\pm$ 3 standard deviation of the original curve.) Linear regression analysis is then performed. Method- and detection limit-specific data are accessed for quantitation and report-writing from each such data set. For reporting accuracy, the algorithm

$$\frac{\begin{array}{c}\text{Linear-Regressed}\\ \text{Raw Concentration}\\ \text{from Calibration Curve}\end{array} \quad \begin{array}{c}\text{Solid Sample}\\ \text{Extract Volume}\\ \text{If Solid}\end{array} \quad \begin{array}{c}\text{Concentration}\\ \text{or}\\ \text{Dilution Factor}\end{array}}{\begin{array}{c}\text{Solid Sample}\\ \text{Mass If Solid}\end{array} \quad \begin{array}{c}\text{Fraction}\\ \text{Solids If Solid}\end{array}} = \begin{array}{c}\text{Final}\\ \text{Concen-}\\ \text{tration}\end{array}$$

is used for all quantitations. (All such algorithm input data are archived for long-term storage.) Detection limits for solids are generated on a per-sample basis and calculated by replacing "LINEAR-REGRESSED RAW CONCENTRATION FROM CALIBRATION CURVE" with "DETECTION LIMIT OF ANALYTE IN LIQUID MATRIX" in the above equation.

WESTON

CHAIN-OF-CUSTODY

Since they document the history of samples, chain-of-custody procedures are a crucial part of a sampling/analysis program. Chain-of-custody documentation enables identification and tracking of a sample from collection to analysis to reporting.

WESTON's chain-of-custody program necessitates the use of EPA-approved sample labels, secure custody, and attendant recordkeeping. Depending on the client's requirements, WESTON also offers container sealing during unattended transportation of samples.

In essence, WESTON considers a sample in custody if it: is in a WESTON employee's physical possession; it is in view of that WESTON employee; is secured by that WESTON employee to prevent tampering; or is secured by that WESTON employee in an area that is restricted to authorized personnel.

Each time a sample is relinquished from one analyst to another or from one major location to another, WESTON's analytical personnel are required to make appropriate entries. Personnel-specific initials are used as identifiers of analysts, as are location codes for various locations (refrigerators, extraction areas, analytical areas, etc.) within the laboratory. Each transaction for each sample is accompanied by a specific reason for transfer. Chain-of-custody documentation is given in Appendix G.

QA/QC OFFICER

Toward maintenance of a rigid, credible QA/QC regimen, WESTON Analytical Services maintains a full-time, in-house QA/QC officer who retains independent authority to declare out-of-control situations, thereby precluding reporting of unacceptable data. The QA/QC officer has been available, as needed, on the project.